REPORT 54

SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMELIORATION

DU MILIEU PEDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

RAINFALL SIMULATION TO EVALUATE EROSION CONTROL ON TED RESEARCH SITES

FINAL REPORT

July, 1992

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EXECUTIVE SUMMARY

Rainfall simulations were conducted in 1989, 1990 and 1991 on twenty two occasions at fourteen different farms. A wide range of conservation farming systems, involving different tillage, cover crop and manure management systems, were evaluated in terms of runoff and soil and phosphorus losses resulting from a simulated rainstorm.

The rainfall simulations took place on research plots set up within ongoing TED studies, following consultation with the TED research contractor and the farmer cooperator. Runoff and erosion data were collected within one set of replications set up under the main research trials.

The erosion control offered by aeration tillage, reduced tillage (using a chisel plow or offset disk) and zero-tillage systems was evaluated, and compared against a conventional (moldboard plow) tillage system. At some sites, the erosion control provided by cover crops of red clover, rye, barley, annual ryegrass, hairy vetch or oilseed radish was compared against treatments where the only surface residue cover was from the previous main crop. The susceptibility of soils to erosion and phosphorus losses following applications of raw and composted beef manure, and liquid swine manure was also examined.

The runoff and erosion data provided by the rainfall simulations were highly variable at many of the sites. However several trends emerged from the research. In most cases, the conservation tillage systems resulted in reduced runoff and erosion rates. Aerway®[1] tillage shows promise as an effective management tool for high residue cropping systems. It leaves sufficient residue on the surface to reduce the amount of soil detachment and erosion due to rainfall, and does not appear to lower the infiltration rates in comparison with moldboard plow tillage, as indicated by runoff volumes. Furthermore, it can be pulled in tandem with the planter, providing secondary tillage with relatively little soil disturbance.

Reduced tillage systems tended to lessen the amount of sediment loss due to the simulated rainstorm, in comparison with moldboard plow tillage. In most cases, the degree of control over sediment losses was proportional to the amount of residue cover remaining on the surface and the amount of disturbance to the soil surface by the tillage operation.

Many cover crop systems were tested by rainfall simulation. When they were growing, or had been killed but not disturbed by tillage, they provided nearly complete surface cover and appeared to be equally effective in controlling soil erosion. After spring cultivation and planting, some cover crops, most notably hairy vetch, appeared to provide lasting erosion

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[1] inclusion of brand names does not imply endorsement of use.

control benefits, possibly due to soil structural improvements and persistent surface residue. Other cover crops, in particular oilseed radish, provided no lasting erosion control benefits. In general, the residue from cover crops with more fibrous plant growth was more persistent and effective in controlling soil erosion.

Applications of raw and composted beef manure in summer onto perennial forages and applications of liquid swine manure in summer and spring did not affect erosion rates or phosphorus losses in comparison with similar treatments where manure was not applied. However, when poultry manure was applied in the fall and incorporated by aerway tillage only, soluble orthophosphate-P losses by rainfall simulation were very high (3.6 mg/m^2) in comparison with losses of 0.13 mg/m^2 when the manure was incorporated by moldboard plowing.

Several factors contributed to high variability or possible non-treatment related differences in the rainfall simulation results. Soil cracks on some plots caused major reductions in runoff. Due to the experimental set-up, the slopes of some treatments were significantly different than the slopes of the treatments to which they were being compared. Nevertheless, many of the rainfall simulations provided excellent results and demonstrated that reductions in soil and phosphorus erosion can be achieved by the adoption of conservation farming measures.

ACKNOWLEDGEMENTS

This research would not have been possible without the time and assistance provided by the farmer cooperators, whose names are included with the title of each experiment. In addition, we would like to thank Dr. W.I. Findlay, the Scientific Authority for the TED program, for his insight and his enthusiasm about the rainfall simulation studies, and for the craftsmanship he displayed in personally constructing many of the key components of the rainfall simulator used in these experiments.

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1. INTRODUCTION

During a planning and modelling workshop hosted by TED in November 1988, gaps were identified in the data being collected within the TED research. Many of the TED research projects were not obtaining data to quantify or evaluate the degree of erosion control provided by the farm management practices or technologies being tested. In order to address the gaps identified during the November 1988 workshop, TED collected runoff and erosion data on selected TED research sites in 1989, 1990 and 1991.

Rainfall simulation was used as the tool to collect the runoff and erosion data. The Guelph Rainfall Simulator II (Tossell *et al.*, 1987) was used, and the method of Agriculture Canada (G. Wall, personal communication) was followed under the initial direction of their staff at the Ontario Institute of Pedology (see Page 6).

Rainfall simulations were conducted on research plots set up within ongoing TED studies, following consultation with the TED research contractor and the farmer cooperator. Runoff volumes and soil and phosphorus loss data were collected within one set of replications set up under the main research trials.

This report provides a general background on soil erosion parameters, previous research with rainfall simulators and a description of the methods used in the TED rainfall simulation studies. Finally, the results of the each of the rainfall simulations on individual TED research projects are presented for each of the three field seasons.

2. Literature Review

2.1 The Universal Soil Loss Equation

Wischmeier and Smith (1978) looked at five main factors that affect the amount of runoff and erosion losses from agricultural fields. They developed the Universal Soil Loss Equation (USLE), which combined these factors to predict long term average annual soil losses from farm fields under specific conditions. A description of the five USLE factors follows:

R - Rainfall and Runoff factor: This factor describes the effect of raindrop impact and the amount and rate of runoff associated with that rain. Rainfall erosion indices and the temporal distribution of rainfall erosion have been calculated for Canada east of the Rocky Mountains (Wall *et al.*, 1983).

K - Soil Erodibility Factor: This factor describes the soil's natural susceptibility to erosion. An annual K value may be obtained from a nomograph which relates % silt + very fine sand, percent sand, % O.M., soil structure and permeability class to erodibility. An attempt has been made to characterize K and seasonal differences in K with soil properties such as shear strength, antecedent moisture, and aggregate stability (Wall *et al.*,1988; Coote *et al.*, 1988).

LS - Topographic factor: This factor incorporates the effects of length and steepness of the slope and specifically is the expected soil loss relative to that from a uniform 9% slope, 22.1 m long.

C - Cover and Management Factor: This factor describes the combined effects of cover and management and includes consideration of rotation, previous cover, and the length of time between successive crop canopies. It expresses the soil loss relative to clean-tilled continuous fallow. The C factor is particular to locality because its value combines expected periods of highly erosive rainfall with corresponding periods of plant cover. The year is divided into crop-stage periods according to percent cover; approximate time frames of the corresponding crop stage periods are shown:

rough fallow (Apr,May)
seedbed (May)
establishment (June)
development (Jul,Aug)
maturing crop (Sept,Oct)
residue or stubble (Nov-Apr)

The C factor considers crop canopy, residue mulch and the effects of incorporation of residues into the soil surface by tillage.

P - Support Practice Factor: This factor describes the soil loss with a support practice such as contouring or strip cropping on the contour, relative to loss with up and down slope cultivation.

Although the USLE was designed to predict long-term average annual erosion rates, in application, the equation has been modified and used to predict soil loss from a single rainfall event (Foster, 1988). In this application a single C-factor based on soil cover and rainfall erosivity at the time of the storm was used.

2.2 The Use of Rainfall Simulation to Study Erosion

Rainfall simulation can be used to compare erosion and runoff losses from agricultural practices. Agricultural practices affect the magnitude of the C-factor in the USLE. The TED studies on which rainfall simulation was carried out manipulated the cover and management factor through combinations of tillage and cover crops. By varying soil and cover crop management, the crop stage periods in which the ground surface is adequately covered can be extended.

Rainfall simulation was also used to evaluate the effectiveness of erosion control practices such as reduced tillage and cover cropping as a means of controlling runoff and nutrient losses from manured sites.

Data obtained from rainfall simulation studies indicate relative rates of erosion. To determine absolute values for annual erosion rates, the long-term erosion rates from natural rainfall studies would need to be determined. The relationship of natural to simulated erosion can be assumed to be constant for a given set of conditions (Meyer, 1988). Most researchers have chosen to report fractional reductions in simulated runoff, soil or nutrient losses from a practice, relative to a conventional practice rather than to imply some long term erosion losses resulting from the use of a practice.

The USLE incorporates the effects of rill and interrill erosion. Rainfall simulation, as used in the TED studies, simulates the effects of a rainstorm on 1 m^2 plots and isolates and measures the effects of interrill processes only. The implication of this is that the erosion losses calculated from rainfall simulation studies cannot translate into a contribution of specific reductions in soil and phosphorus that contribute to the SWEEP goal of a 200 tonne phosphorus reduction for Lake Erie. The measurements may be used however, to gain a better understanding of the effects of different conservation farming practices on soil and phosphorus losses related to interrill soil erosion by water.

Rainfall simulation has been used to evaluate the impacts of tillage and residue levels on nutrient and sediment losses (Barisas *et al.*, 1978; Mostaghimi *et al.*,1988). When different tillage operations left varying residue levels, it was found that conservation tillage reduced N & P losses, compared to conventional practices. However, the more residue cover present, the greater the loss of soluble N & P, although this amount was considerably less than the loss of nutrients carried by the sediment fraction (Barisas *et al.*, 1978). Conservation tillage was believed to contribute to greater water soluble nutrients in runoff because of leaching from plant residues and reduced incorporation of fertilizer.

Laflen *et al.*, (1978) suggested that differences in percent soil cover can explain the variability in soil loss from most tillage systems during the cropping season before canopy development. They observed that sediment concentration in runoff water was inversely related to the amount

of ground cover. Their data showed that sediment concentration and soil loss decreased to near zero on two out of three soils when a 40 to 65 percent residue level was reached. At very high residue levels, it appeared that residue level was not linearly related to soil loss. Runoff volume did not decline as steeply as sediment loading with increasing residue cover.

Similarly, Andraski *et al.* (1985a) suggested the relation of runoff and residue cover is not linear. They recorded the response of 4.6 x 22.1 metre plots within fall moldboard plowed, fall chisel plowed, fall till-planted and no-till treatments under a range of natural rainfall events. Over a three year period, the average surface residue cover after planting was 1, 24, 24 and 68% for the moldboard, chisel, till-plant and no-till treatments respectively. The moldboard plowed treatment yielded significantly more runoff for all four of the runoff events that were successfully monitored. While there were no significant differences between the runoff volumes of the conservation tillage treatments, during three of the four runoff events the fall chisel plowed soil had less runoff per unit of rainfall depth than either fall till-plant or no-till. The authors suggested that the chisel plowed soil had better internal drainage, which appeared to have lessened the influence of the five day antecedent rainfall on the soil moisture of the chisel plowed treatment.

Under simulated rainfall, Andraski *et al.* (1985a) observed no differences in runoff among conservation tillage systems. Conservation tillage had lower runoff than conventional (Andraski *et al.*, 1985a). Andraski *et al.* (1985b) found that no-till had consistently less soil loss than conventional tillage over all periods (June, July, October measurements) while for the other conservation tillage methods studied, chisel and till-plant reductions in soil loss relative to conventional tillage varied according to the period in which the measurements were made.

A study which attempted to distinguish between tillage and residue factors in erosion losses found that runoff and sediment losses decreased as residue levels increased from 0 to 750, to 1500 kg rye residue/ha under conventional and no-tillage systems (Mostaghimi *et al.*, 1988). No-till reduced soil loss by 97 to 99% relative to conventional tillage. The total resulting phosphorus losses from sediment and runoff were greatest for each tillage treatment without residue with values for no-till (10 mg/m^2) considerably less than those for conventional tillage (524 mg/m^2). Soluble orthophosphate-P yields were greatest where there was no residue, least where residue was 750 kg/ha and intermediate at the highest residue level. The higher orthophosphate losses from the 1500 kg/ha residue level than from the 750 kg/ha residue level were attributed to: (i) release of phosphorus from the residue; (ii) less runoff to dilute the readily leachable P; and, (iii) greater interception of fertilizer phosphorus by the residue (Mostaghimi *et al.*, 1988).

It was suggested that tillage systems that control erosion do not necessarily reduce losses of soluble N and P where fertilizers are surface applied (Romkens *et al.*, 1973). Under conventional tillage, no differences in PO_4-P,NO_3-N and NH_4-N in runoff water were found

between fertilized and unfertilized areas, whereas all conservation tillage treatments had greater soluble nutrient losses where the soil was fertilized.

The method of fertilizer placement becomes important in controlling nutrient losses in conservation tillage systems. Mueller (1984) reported high soluble phosphorus levels in runoff from soils where manure was not completely incorporated by tillage, compared to soils where the manure was incorporated. Also, sediment in the runoff from a conservation tillage system contained greater concentrations of N and P relative to conventional tillage. It was suggested that tillage systems that leave a greater amount of residue or rougher soil surface (chisel, coulter) trap large silt and sand-size particles and therefore yield sediments that contain relatively higher amounts of clay, and thus, higher phosphorus concentrations in the runoff sediment, compared with systems that are less rough at the soil surface.

Kramer (1986) collected runoff and soil loss data from natural runoff plots in Missouri over 24 years. Conventional and conservation tilled corn were compared for the magnitude and distribution of erosion losses according to crop stage. Soil loss from conventional tillage averaged 603 g/m^2 annually and conservation tillage averaged a soil loss of 256 g/m^2 per year. Half of the annual soil loss from the conventional tilled corn occurred during the seedbed stage (May-June) while the conservation tillage system lost one third of its annual total in this period. Residues left from chisel tillage were effective in reducing soil loss relative to moldboard and disking. The greatest losses of soil and runoff for both tillage treatments were during the seedbed stage (mid-May to mid-June) when the corn provided little canopy cover. The annual distribution of runoff paralleled that for precipitation for both tillage methods.

While the C-factor has been shown to vary with the time of year, soil erodibility or the soil's susceptibility to erosion is also known to change seasonally (Wall *et al.*, 1988; Coote *et al.*, 1988). In these reports, field data were compared with computed values from rainfall simulation in the lab for soil erodibility (K) and seasonal erodibility (K_s). On the sand, silty clay and silt loam soils in the lab, the greatest K_s values occurred during the simulated winter-spring thaw period, when soil moisture was high and internal drainage poor. This pattern corresponded to what was found in the field. Field values from K_s were higher and ranged more widely through the year than those in the lab. The magnitude of the seasonal variations in soil erodibility varied according to soil texture; fine textured soils tended to increase in soil shear strength on warming while the shear strength of coarse-textured soils changed little.

Seasonal variations in shear strength of soils were measured and its reciprocal used as an index of soil erodibility (Coote *et al.*, 1988). The resulting values for K_r (K_s/K = seasonal K/annual K) were between those estimated in the field and lab. Similarly, temporal changes in shear strength and aggregate stability related in part to changes in soil moisture. Based on the use of these soil erodibility indices it was concluded that soils are more susceptible to erosion under thaw and spring conditions than later in the season (Coote *et al.*, 1988). The high

erodibility of soils during spring thaw was attributed to the freezing, thawing, and saturation at this time.

A range of rainstorm intensities and durations and rainfall simulation plot sizes have been used by researchers. This makes the comparison of the effects of a practice measured by different researchers difficult to compare. Conditions under which the TED research was conducted most closely resembled studies conducted by Agriculture Canada (Wall *et al.*, 1991) in southwestern Ontario, in terms of intensity and duration. In that study, rainfall simulations were conducted four times per year over two years on corn residue, with and without an interseeded red clover crop. Runoff volume and sediment losses were significantly reduced in the corn/clover system most of the time, compared with a corn system (Wall *et al.*, 1991).

3. Methods

3.1 Simulated Rainfall

Rainfall simulation was carried out with a Guelph Rainfall Simulator II (GRS II) using the method developed by Agriculture Canada and commonly used in Southern Ontario for erosion studies (Tossell *et al.*, 1987; Wall *et al.*, 1991). Plots were defined by a 1 m^2 border and the runoff collection trough was oriented perpendicular to the direction of the slope and to the direction of planting the main crop, unless otherwise noted.

Measurements of the slope and soil cover within the plot area were made before conducting the rainfall simulations. Plot slope was measured using a metre stick, a carpenter's level and a ruler to measure the vertical displacement from the upper to lower end of the plot. The slope of the plot is a measure of the microtopography. Thus, the micro slope of the plot could differ from the gradient, or macro-scale slope of the hill where the plots were located.

Soil residue cover was estimated using a variation of the knotted rope method. A 1.2 metre long piece of wooden dowelling marked at 4 cm intervals was placed across the plot at right angles to the plot border. The number of times (to a maximum of 25) when residue was found directly beneath a mark was counted. The percentage residue cover of the 1 m^2 plot was obtained by adding the residue count from four different placements across the plot.

Before each simulation, a soil sample was collected from the upper 15 cm layer adjacent to each plot. The soil samples were weighed, dried, then weighed again to determine the gravimetric moisture content. In 1989, the soils were air dried over a five day period. In 1990, the samples were dried for 24 hours in an oven at 105°C. In 1991, the soil samples were brought to the Analytical Services Laboratory at the University of Guelph for gravimetric soil moisture analysis.

A composite surface soil sample was obtained from each site and analyzed for fertility (P, K, Mg), pH, texture and % organic matter by the Analytical Services Laboratory at the University of Guelph.

For the May 9-12, 1989 simulations, the rainstorm was achieved with a 3/8" nozzle positioned 1.1 metres above the ground surface. The rain intensity was 53.8 mm/h, lasted 20 minutes and simulated a rainfall frequency of approximately a 1 in 2 year event (AES, 1986). The accumulation over the 20 minute simulation was 17.9 mm.

A 1/2" nozzle positioned 1.5 metres above the ground surface was used for all of the other simulated rainstorms conducted in 1989, 1990 and 1991. A constant water pressure of 48.3 kPa (7 psi) produced a 154.8 mm/h rain intensity over the plot. This resulted in an accumulation of 25.8 mm (1.0") from the 10 minute storm, simulating a rainfall event of approximately 1 in

50 year frequency (AES, 1986). Over the 1 m^2 rainfall plot, the 25.8 mm depth of water translates into a volume of 25.8 litres (5.7 Imp. gallons).

On some occasions, a 10 minute rain storm was insufficient to yield runoff at a site. In 1989 and 1990, TED rainfall simulations were always terminated after 10 minutes, with the result that some sites yielded little or no runoff data. For the 1991 field season, when a 10 minute storm was insufficient to yield runoff, the duration of the simulation was extended to 15 minutes for all treatments and repetitions. This resulted in an accumulation of 37.7 mm (1.5") from the 15 minute storm, simulating a rainfall event of approximately 1 in 100 year frequency (AES, 1986). The 37.8 mm depth of water corresponds to a volume of 37.8 litres (8.3 Imp. gallons) over the 1 m^2 rainfall plot, or 12.9 litres more than the 10 minute simulations. The additional 5 minutes of rainfall was sufficient to produce runoff data from all but two repetitions (on different treatments) at one site in 1991.

Rainfall simulations were conducted on research plots set up within ongoing TED studies, following consultation with the TED research contractor and the farmer cooperator. Except where noted otherwise in the individual site descriptions, runoff data were collected within one set of replications set up under the main research trials. Rainfall simulations were confined to as few as possible of the experimental replications for each treatment in order to minimize the extent of the damage caused by performing rainfall simulations.

In Years 1 and 2 of the study (1989 and 1990), the rainfall runs were replicated three times on separate 1 m^2 plots within each research plot or treatment. In Year 3 (1991), the number of replications was increased to four.

Total runoff volume was measured and recorded at the end of each simulation. The entire runoff sample was mixed thoroughly in a large bucket and a 0.5 litre subsample was collected for analysis of sediment phosphorus concentrations. Using a syringe, 5 ml was drawn from this subsample and filtered through a 0.45 μm filter paper into a vacutainer tube for soluble orthophosphate-P analysis.

A sample was collected from each water source used in the simulations. Lab analysis revealed no detectable amount of phosphorus in the water from any of the sources.

3.2 LAB ANALYSES

The lab analysis was performed by the Analytical Services Laboratory of the University of Guelph, under the direction of E. Gagnon. The sediment concentration of the runoff subsamples was determined by allowing the sediment in the runoff sample to settle, decanting the clear portion of the runoff sample (usually about 90% of the 0.5 L sample), and evaporating the remainder of the sample to dryness. In using the evaporation method rather than filtration, the contribution of salts to the weight of the sediment was assumed to be negligible.

Sediment, obtained by the process described above, was digested using a sulfuric acid-nitric acid digestion to determine sediment phosphorus. Total phosphorus in the sediment was converted to orthophosphates which were measured colorimetrically, by development of the molybdenum blue colour using stannous chloride in a Technicon by Auto-Analyzer (American Public Health Association *et al.*, 1975).

Soluble orthophosphate-P was measured in the filtered runoff solution colorimetrically as outlined above.

4. Study Findings: Year 1 (1989 Field Season)

Rainfall simulations were conducted in May, July, September and November of 1989 at the farms of five TED research cooperators. Runoff, soil and phosphorus losses were measured on the research plots of experiments dealing with cover crops, reduced tillage, aeration tillage and manure management systems.

4.1 Erosion Control Resulting from Fall Planted Cereals after Soybeans (M. Lobb Farm, May 1989)

4.1.1 Site Description

Fall rye and spring barley were planted to provide soil cover following soybeans by either of two methods: (i) broadcast at leaf drop, or (ii) drilled in after harvest and following tillage. Rainfall simulation was used to test the effect of the cover the following spring, on the reduction of runoff, sediment and phosphorus losses relative to where the ground was left without a fall seeded cereal cover.

The site was located on the farm of M. Lobb, Goderich Township, Huron County. Rainfall simulation was carried out May 9-12, 1989. The rotation was soybeans following no-till corn. The runoff collection troughs were oriented perpendicular to the direction of the slope and to the direction of planting the main crop.

The composite sample of the surface soil at the site had a silt loam texture with a soil test phosphorus level of 16 mg/kg, a pH of 7.5 and an organic matter content of 2.9%.

The rainstorm used at this site was achieved with a 3/8" nozzle positioned 1.1 metres above the ground surface. The rain intensity was 53.8 mm/h, lasted 20 minutes and simulated a rainfall frequency of approximately a 1 in 2 year event (AES, 1986).

4.1.2 Statistical Analyses

Statistical analyses were conducted on data using analysis of variance (ANOVA); degrees of freedom for treatment effects were partitioned into single degree of freedom orthogonal comparisons. Significance was determined at $p \leq 0.10$.

4.1.3 Results and Discussion

Ground cover and Slope:

The tillage and cropping system provided relatively high amounts of ground cover (Table 4.1). Tillage (tandem disk) followed by drilling of the cereals resulted in significantly less surface cover (48%) compared to the surface cover when the wheat was broadcast seeded

at leaf drop (67%). The ground cover averaged 50% where no cereal cover crop had been planted.

Table 4.1 Data from Rainfall Simulations Conducted on May 9-12, 1989, at the Farm of M. Lobb, Huron County. (53.8 mm/h intensity for 20 minutes)

Cover Crop	Method of Establishment	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)
Rye	Broadcast at Leaf Drop	3.4	73	6.7	1.1	2.4	1.77
Rye	Till and Drill	2.8	48	5.3	2.7	8.5	6.49
Barley	Broadcast at Leaf Drop	4.0	61	7.2	1.9	4.5	4.07
Barley	Till and Drill	2.8	47	10.1	1.3	5.2	4.52
Control (no cereal cover)		4.1	50	6.7	1.8	3.8	2.93
Probability That the Difference Between Means of Specified Contrast is Zero							
Rye vs. Barley		0.707	0.415	0.255	0.786	0.872	0.950
Cover vs. No Cover		0.348	0.431	0.805	0.963	0.720	0.674
Leaf Drop vs. Till & Drill		0.273	0.025	0.709	0.592	0.326	0.345
Cover x Method Interaction		0.707	0.464	0.347	0.285	0.426	0.432

Surface cover was high for all treatments because of the farmer's consistent no-till system of management. The "bare ground" was already well covered with residues from the previous year's soybean crop and corn residues from two years previous.

The average treatment slopes ranged from 2.8 to 4.1%, with an average for the site of 3.4%. There were no significant differences between the slopes of any of the treatments.

SOIL MOISTURE:

The soil moisture at the time of the rainfall measurements did not differ significantly as a result of the tillage and cover crop treatments. The air dried soil moisture averaged 7.2% by weight at the time of the rain trials.

RUNOFF VOLUME:

Runoff volumes within both of the rye treatments, but particularly the rye till and drill treatment were highly variable (Figure 4.1). As a result, the rye till and drill treatment had the highest average runoff volume, at 2.68 L/m^2 (Table 4.1), despite two of the three repetitions producing 0.8 L/m^2 of runoff (Figure 4.1). All of the other average runoff volumes were lower than the rye till and drill, and ranged from 1.05 to 1.88 L/m^2. Low

runoff volumes at this site were likely the result of many factors, including dry soils, high residue levels, and the low (53.8 mm/h) intensity rainstorm used. This intensity would generate less runoff than the higher (154.8 mm/h) intensity rainstorms used for all subsequent rainfall simulations.

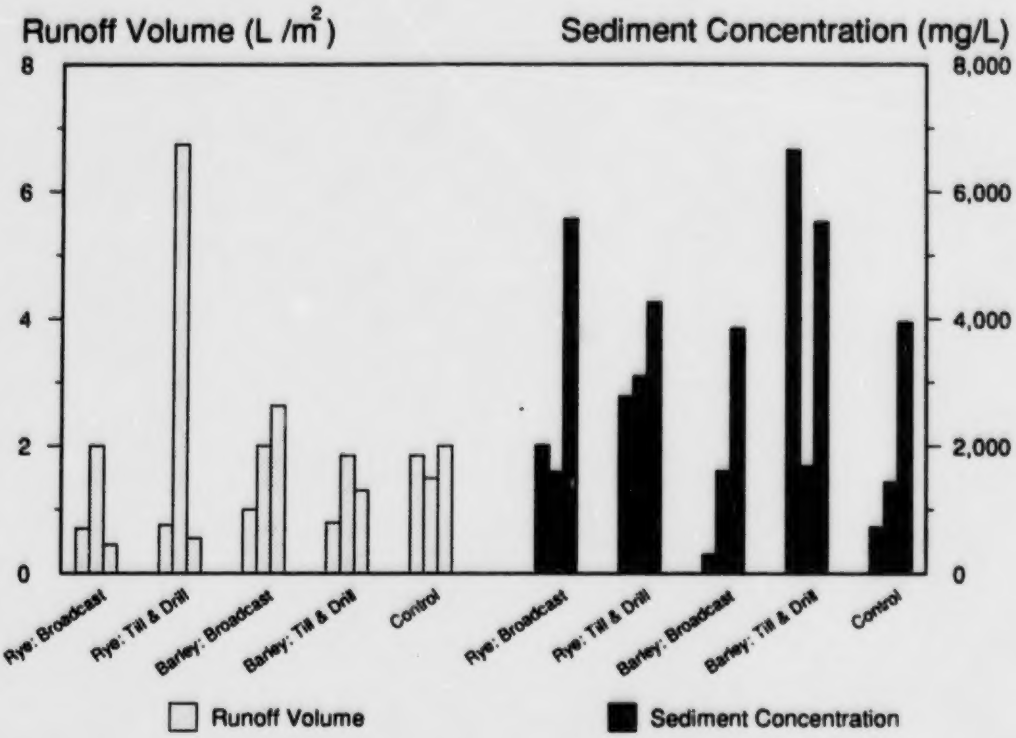

Figure 4.1. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the M. Lobb farm in May, 1989.

Soil Loss:

Concentrations of sediment in the runoff were highly variable within all but the rye till and drill treatment (Figure 4.1). The average sediment concentration for all of the treatments was 3001 mg/L. There were no significant differences in the amount of soil loss from the different treatments (Table 4.1). The rye till and drill treatment, with the highest average runoff, also had the highest average soil loss, at 8.45 g/m^2. Soil loss from all plots averaged 4.9 g/m^2. The treatment where rye was broadcast at leaf drop was the only treatment to have less soil loss than the control.

PHOSPHORUS:

Sediment phosphorus loss ranged from 1.77 to 6.49 mg/m^2, with an average of 3.9 mg/m^2 (Table 4.1). There were no significant differences in the amount of sediment phosphorus lost from any of the treatments. No soluble orthophosphates were detected in the filtered runoff.

SUMMARY:

When subjected to a 20 minute, low intensity simulated rainstorm, a fall rye or a spring barley cover crop provided no significant benefits in terms of soil and phosphorus erosion control over that provided by the previous year's no-till soybean residue.

4.2 EROSION CONTROL RESULTING FROM FALL AND SPRING KILLED RED CLOVER USING CHEMICAL OR MECHANICAL METHODS (W. TEBBUTT FARM, MAY 1989)

4.2.1 SITE DESCRIPTION

Red clover had been established in winter wheat and was killed by either chemical desiccation (2,4-D, atrazine and oil) or by moldboard plowing in either fall 1988 or spring 1989. Rainfall simulation was carried out May 29-30, 1989, after corn planting, to test the effect of the method and timing of killing the cover crop on the amount of runoff, sediment and phosphorus losses.

The site was located on the farm of W. Tebbutt, Goderich Township, Huron County. The composite sample of the surface soil at the site had a loam texture with a soil test phosphorus level of 16 mg/kg, a pH of 7.3 and an organic matter content of 5.6%.

4.2.2 STATISTICAL ANALYSES:

Statistical analyses were conducted on data using analysis of variance (ANOVA); degrees of freedom for treatment effects were partitioned into single degree of freedom orthogonal comparisons. Significance was determined at $p \leq 0.10$.

4.2.3 RESULTS AND DISCUSSION

GROUND COVER AND SLOPE:

The treatments in this experiment were more varied in surface cover and surface roughness than the previous experiment which involved all no-till methods. The average surface cover was 80% where the ground had not been plowed, significantly greater than the average 6% residue cover from the two plowed treatments (Table 4.2). The spring chemically killed red clover treatment had an almost complete surface cover of 92%, which was significantly greater than the 67% residue cover on the fall chemical killed treatment.

Table 4.2. Data from Rainfall Simulations Conducted on May 29-30, 1989, at the Farm of W. Tebbutt, Huron County. (154.8 mm/h intensity for 10 minutes)

Kill Type	Timing	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)	Ortho P Loss (mg/m²)
Chemical	Fall '88	8.3	67	14.1	3.9	15.3	18.7	0.580
Chemical	Spring '89	8.8	92	15.4	2.9	3.6	4.8	0.301
Moldboard	Fall '88	10.0	6	16.1	6.6	51.5	63.9	0.151
Moldboard	Spring '89	8.8	6	11.7	7.3	72.4	87.1	0.161
Probability That the Difference Between Means of Specified Contrast is Zero								
Chemical vs. Moldboard		0.419	0.000	0.289	0.030	0.014	0.014	0.221
Chemical: Fall vs. Spring		0.727	0.000	0.716	0.619	0.636	0.643	0.381
Moldboard: Fall vs. Spring		0.424	0.893	0.041	0.731	0.403	0.445	0.974

The site had an average slope of 9%. There were no significant differences in the slopes of the different treatments.

SOIL MOISTURE:

At the time of the rainulator studies, the air dried moisture of the soil averaged 13.5%. The fall plowed treatment had a significantly higher soil moisture than the spring plowed treatment (Table 4.2).

RUNOFF VOLUME:

The runoff volumes from each of the three repetitions on the four treatments are shown in Figure 4.2. Runoff volumes were relatively consistent within each treatment, except for the spring chemical kill treatment, which had two low yielding repetitions and one which had a similar runoff volume to the mechanical kill treatments. Average runoff volumes were considerably less from the chemically killed red clover treatment compared with the moldboard plow killed treatments (Table 4.2). The mechanical kill resulted in twice the runoff of the chemical kill treatments (6.9 L/m² vs. 3.4 L/m²).

The results agree with studies by Andraski *et al.* (1985a, 1985b), who found that no-till, as well as chisel plow and till-plant, reduced runoff and soil loss relative to conventional tillage. Other studies have shown greater (Mueller *et al.*, 1984) or no differences (Laflen *et al.*, 1978) in runoff from no-till treatments compared to plowed treatments. It is not known under what conditions the no-till system will generate less runoff relative to a moldboard plowed system. It has been suggested that surface crusting due to previous rainfalls on plowed soil may be responsible for increased runoff from conventionally tilled treatments (Andraski *et al.*, 1985b).

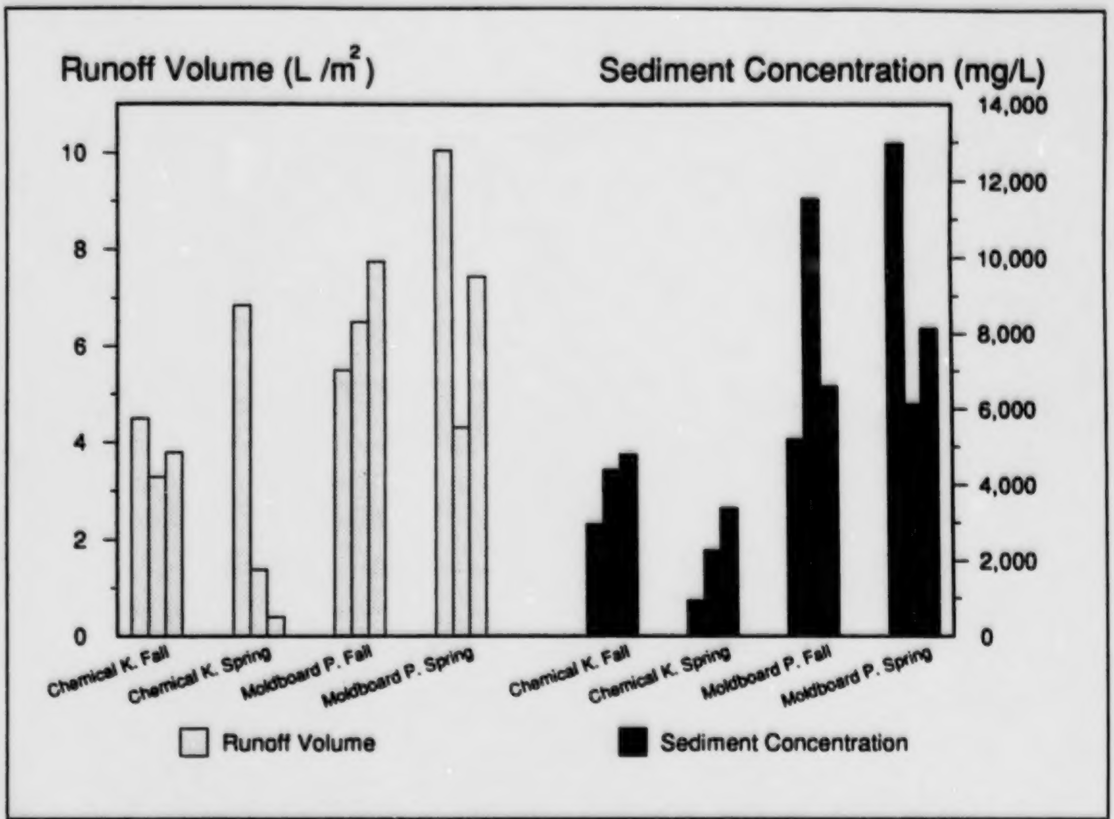

Figure 4.2. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the W. Tebbutt farm in May, 1989.

Soil Loss:

The spring chemically killed treatment had the lowest concentrations of sediment in the runoff while runoff from the spring mechanically killed treatment had the highest sediment concentrations (Figure 4.2). The higher sediment concentration in combination with the greater amount of runoff resulted in much greater soil loss from the mechanically killed plots. Where the clover had been chemically killed, the soil loss averaged 9.5 g/m^2 while the average soil loss from the two mechanically killed treatments was 62 g/m^2. The amount of soil loss was significantly reduced as a result of not using the moldboard plow to eliminate the red clover (Table 4.2). Proportionally higher soil loss relative to the differences in runoff between plowed and no-till soils were a consequence of the higher sediment concentration in the runoff from the plowed soil, as shown in Figure 4.2.

There were no significant differences between the amount of soil loss from the fall versus spring chemically killed treatments, although the average soil loss from the fall chemically killed treatment was over four times greater than the soil loss from the spring chemically

killed treatment (Table 4.2). Soil loss from the fall versus spring mechanically killed treatments was not significantly different, although the spring mechanically killed treatment had the greater amount of soil loss. It is possible that the benefits of having the red clover cover crop over the winter would outweigh any increased susceptibility to erosion in the period immediately following spring plowing.

PHOSPHORUS:

Sediment phosphorus concentrations were similar for all treatments and averaged 1.2 g P/kg sediment. Since losses of runoff and soil were greater for the moldboard plowed treatments than for the chemical kill treatments, the sediment bound phosphorus losses were also greater. The average sediment phosphorus loss from the plowed treatment, at 75.5 mg/m^2, was over six times greater (significant at $p \leq 0.025$) than the 11.8 mg/m^2 average loss from the chemically killed treatment (Table 4.2).

Although sediment phosphorus losses from the fall chemically killed treatment, at 18.7 mg/m^2 were almost four times greater than from the spring chemically killed treatment, the difference was not significant (Table 4.2). Thus, the additional residue cover on the spring killed treatment was not providing significantly better control of soil phosphorus losses.

Soluble orthophosphate-P concentrations in the runoff from the chemically killed treatments were ten times (0.22 mg/L) those of the plowed soil (0.02 mg/L). However, the total loss of soluble orthophosphates did not differ significantly among treatments since the volumes of runoff were so much higher for the plowed soil relative to the no-till. The loss of soluble orthophosphate-P from the runoff averaged 0.298 mg/m^2 for all methods of red clover management.

SUMMARY:

When red clover is underseeded in winter wheat, its erosion control benefits the following spring are significantly improved if it is killed by chemical spray application, rather than by tillage. The timing of the chemical application (fall or spring) did not significantly affect the performance of the red clover residue in controlling erosion. The 92% residue cover of the spring killed red clover was not significantly more effective in controlling erosion than the 67% cover provided by the fall killed clover.

4.3 RUNOFF, SEDIMENT AND PHOSPHORUS LOSSES RESULTING FROM MANURE APPLICATIONS TO PERENNIAL FORAGES (M. BENDER FARM, JULY 1989)

4.3.1 SITE DESCRIPTION

Manure applications were made to a stand of perennial forages. Raw beef manure was applied at a rate of 20 t/ha, and beef manure compost was applied at a rate of 15 t/ha. A

no-manure control was used. Rainfall simulation was used to test the effect of the manure applications 5 days after its application, on the amount of runoff, sediment and phosphorus losses.

The site was located on the farm of L. Bender, South Easthope Township, Oxford County. The soils on the site were a loam surface texture (22.1 % clay) with a pH of 5.1 and organic matter content of 2.5%. Rainfall simulation was carried out July 13 and 14, 1989.

4.3.2 Statistical Analyses

Statistical analyses were conducted on data using multiple comparisons (Duncan multiple range). Significance was determined at $p \leq 0.10$.

4.3.3 Results and Discussion

No statistically significant differences were detected for any of the parameters measured (Table 4.3). Except for the similar phosphorus losses, these results were not surprising, since the only difference between treatments was what form of manure was used or whether it was applied at all.

Ground cover and slope:

The residue cover, consisting of a thick stand of perennial forage, averaged 97% over all treatments. The average slope of the treatments ranged from 5.8 to 7.4%, with the control (no manure) treatment having the greatest slope.

Table 4.3. Data from Rainfall Simulations Conducted on July 13-14, 1989 at the Farm of M. Bender, Oxford County. (154.8 mm/h intensity for 10 minutes)

Treatment (manure application)	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)	Ortho P Loss (mg/m²)
No Manure	7.4	97	10.3	0.6	0.6	0.67	0.13
Raw Manure	6.3	99	7.3	0.3	0.5	0.53	0.18
Composted Manure	5.8	94	8.1	0.9	1.1	1.35	0.21
Overall Mean	6.5	97	8.6	0.6	0.8	0.85	0.17

None of the means were significantly different at the 0.10 probability level

Soil Moisture:

At the time of the rainfall simulation runs the soils were very dry, with an average air dried gravimetric moisture content of 8.6%.

RUNOFF VOLUME:

The volume of runoff collected from any one rainfall event varied from 0.10 to 1.7 L/m^2 (Figure 4.3), with the composted manure treatment showing the greatest variability. On average, the amount of runoff was low, 0.60 L/m^2 for all three treatments.

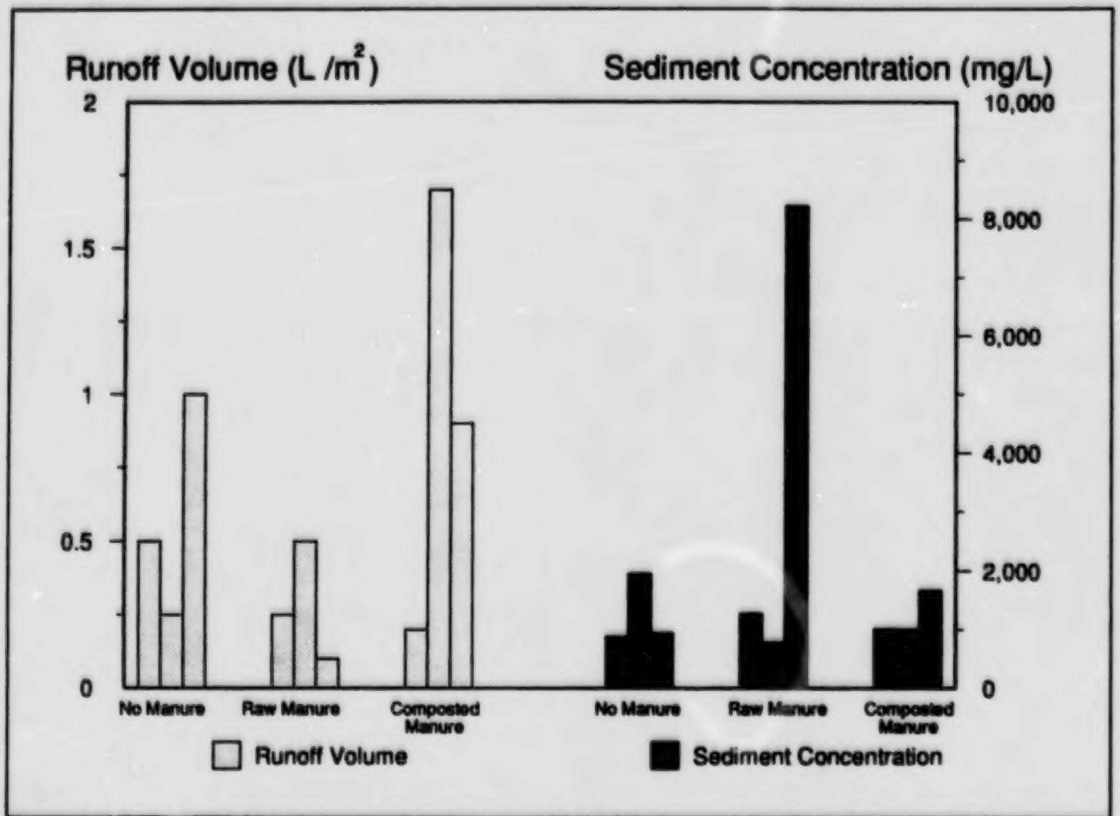

Figure 4.3. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the M. Bender farm in July, 1989.

In hindsight, the rainfall simulations should have been extended to 15 minutes duration at this site. The plots would have yielded a greater amount of runoff, and likely more sediment and phosphorus.

SOIL LOSS:

The sediment concentration of the runoff averaged 2000 mg/L. Sediment concentrations were similar and fairly uniform for all three treatments, except for one of the rainfall simulation runs on the raw manure treatment (Figure 4.3), which had a sediment concentration of 8220 mg/L. However this same run also had the lowest runoff volume (0.10 L/m^2), so the effect of the high sediment concentration on the average soil loss from

that treatment was minor. Soil losses were small during the 10 minute rainstorm, averaging 0.76 g/m^2 (Table 4.3).

PHOSPHORUS LOSS:

Previous research (Mueller, 1984), had shown that surface applications of manure resulted in greater phosphorus losses, from both greater concentrations in the sediment and in solution. In this study, slightly higher phosphorus concentrations were found in the manured treatments. It is not known what proportion of the phosphorus in the runoff originated from the manure source, as samples of the raw and composted manure were not analyzed for phosphorus content.

The average concentration of sediment phosphorus was 1105 and 1150 mg/kg for the raw and composted manure treatments respectively, while the sediment from the control treatment had an average phosphorus concentration of 1034 mg/kg. These concentrations were not significantly different.

The average sediment phosphorus loss for all of the treatments was 0.85 mg/m^2, with the greatest loss coming from the composted manure treatment (Table 4.3). Soluble orthophosphate-P concentrations in the filtered runoff averaged 0.45 mg/L, with the raw manure treatment having the highest concentration (0.90 mg/L). The average soluble orthophosphate-P loss was 0.17 mg/m^2.

SUMMARY:

A mid-summer application of either raw or composted manure applied to the surface of established forages on a moderately (6.5%) sloping field had little or no effect on soil and phosphorus losses relative to where no manure was applied.

4.4 RUNOFF, SEDIMENT AND PHOSPHORUS LOSSES RESULTING FROM AERATION TILLAGE, WITH AND WITHOUT SUBSOILING (J. VAN DORP FARM, SEP. 1989)

4.4.1 SITE DESCRIPTION

In July of 1989, winter wheat was harvested from a sloping field located on the farm of J. Van Dorp, West Oxford Township, Oxford County. In early August, part of the field was subsoiled with a Strohm® subsoiler[1]. Then the field was aerwayed (using the Aerway® tillage tool) and planted to hairy vetch in a single pass. In September 1989, three strips of soil were prepared as sites for rainfall simulation. One of the strips was moldboard plowed. Another strip was aerwayed. A third strip, coinciding with the area that had been aerwayed and subsoiled in August, received no additional tillage in September. The rainfall runs were carried out September 18-19, 1989.

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[1] Inclusion of brand names does not imply endorsement of use.

The tillage operations were conducted perpendicular to the slope of the land (i.e. on the contour), three days prior to the erosion measurements. Rainfall simulation was used to test the effect of aeration tillage, with and without subsoiling, compared to moldboard plowing, on the amount of runoff, sediment and phosphorus losses.

No composite sample of the surface soil at the site was taken. However, one obtained the following year from the same research plots had a silt loam texture with a soil test phosphorus level of 27 mg/kg, a pH of 6.8 and an organic matter content of 3.4%.

4.4.2 Statistical Analyses

Statistical analyses were conducted on data using multiple comparisons (Duncan multiple range). Significance was determined at $p \leq 0.10$.

4.4.3 Results and Discussion

Ground cover and slope:

The aerwayed soil had a residue cover of 37%, which was significantly greater than the 28% cover where the soil was subsoiled in addition to being aerwayed (Table 4.4). The plowed soil had an average surface residue cover of 4%, which was significantly less than both of the aerwayed treatments. The moldboard plow buried the hairy vetch. Most of the hairy vetch cover crop was killed by the aerway pass, but the residue remained on the surface. The hairy vetch continued to grow on the plot that was aerwayed and subsoiled in August.

Table 4.4. Data from Rainfall Simulations Conducted on September 18-19, 1989 at the Farm of J. Van Dorp, Oxford County. (154.8 mm/h intensity for 10 minutes)

Tillage	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Plowed (Sep. '89)	17.2 a	4 c	15.9 b	2.8 a	8.6 a	13.02 a	0.06 a
Aerwayed (Aug. & Sep. '89)	12.7 b	37 a	19.9 a	0.6 b	1.9 b	2.82 b	0.03 a
Aerwayed + Subsoiled (Aug. '89)	12.5 b	28 b	20.3 a	0.8 b	1.7 b	2.65 b	0.03 a

Means in the same column with different letters are significantly different at the 0.10 probability level

The average slope of the rainfall simulation plots on the plowed treatments, at 17%, was significantly greater than the slopes of the aerwayed and aerwayed + subsoiled treatments, which averaged 13% (Table 4.4). The furrows from the moldboard plow operation added to the slope of the plots on the plowed treatment, which ran across the slope. It is likely that the difference in slopes between the treatments influenced the results of the rainfall simulations.

SOIL MOISTURE:

At the time of the rainfall simulation runs the soil had an average air dried gravimetric moisture content of 19%. The plowed treatment had a significantly lower soil moisture content than the two aerwayed treatments (Table 4.4). The greater amount of soil disturbance in the plowed soil may have caused it to dry more rapidly in the three days between tillage and the rainfall simulations.

RUNOFF VOLUME:

Runoff volumes were fairly uniform within each treatment (Figure 4.4). The average runoff volume from the plowed soil, at 2.8 L/m^2, was significantly greater than the runoff volumes from the aerwayed and aerwayed + subsoiled treatments, which averaged 0.6 and 0.8 L/m^2 respectively (Table 4.4).

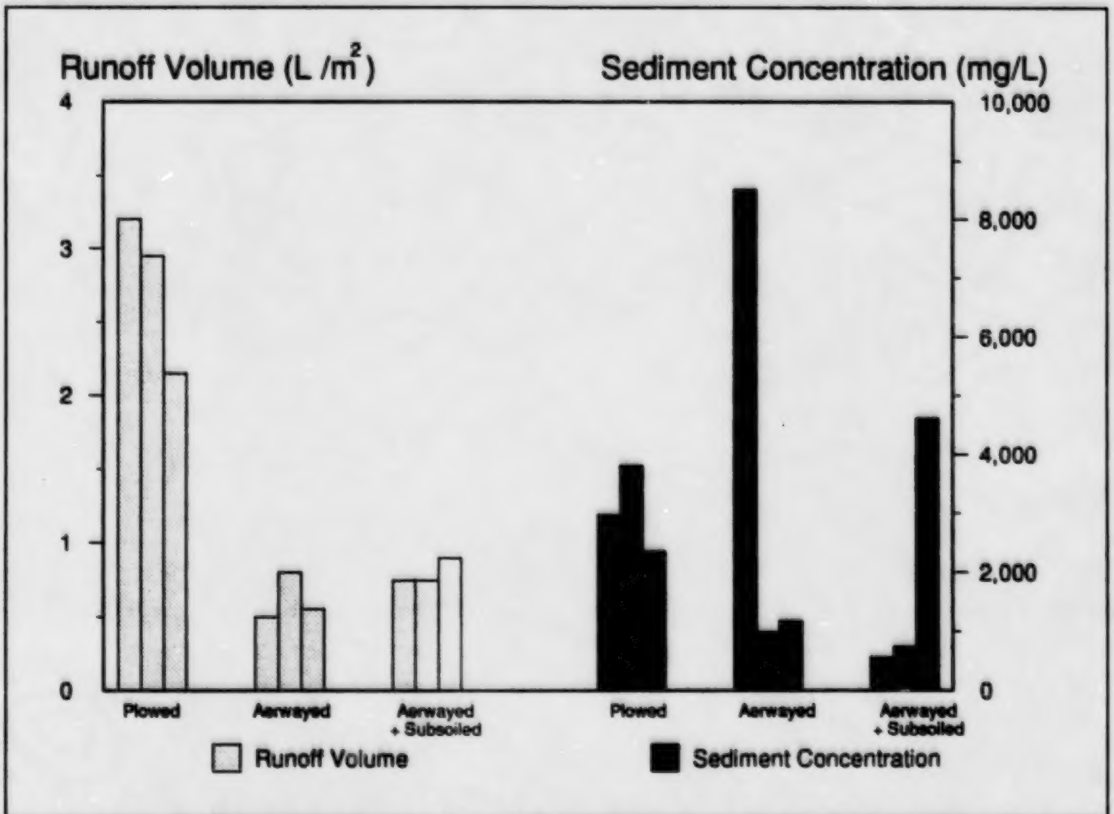

Figure 4.4. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the J. Van Dorp farm in Sep., 1989.

The greater slope of the plots on the plowed treatment may have promoted greater runoff. Also, extensive surface cracking was noted on the soils of many of the plots when rainfall

simulations were conducted on the same three treatments in May and June of 1990. Had similar cracks been present in September 1989, they would have been covered over by moldboard plowing but not by aerwaying. Surface cracks, along with the lifting and fracturing action of the aerway and the subsoiler, could have contributed to the decreased runoff from the aerwayed treatments.

SOIL LOSS:

Both the aerwayed and the aerwayed + subsoiling treatments had two rainfall runs with very low sediment concentrations and one with a high sediment concentration, while the sediment concentrations of the runoff from the plowed treatment were fairly uniform (Figure 4.4). The runoff from the aerwayed treatment had the highest average sediment concentration, at 3554 mg/L, followed by the plowed and aerwayed + subsoiled treatment, with runoff sediment concentrations of 3043 and 1966 mg/L respectively. Since the plowed treatment had a much greater runoff volume, its soil loss was also greater. The average soil loss from the plowed treatment, at 8.6 g/m^2, was significantly greater than the soil loss from the aerwayed and aerwayed + subsoiled treatment, which averaged 1.9 and 1.7 g/m^2 respectively (Table 4.4).

PHOSPHORUS LOSS:

Sediments contained similar concentrations of phosphorus, averaging 1512 mg P/kg soil. Owing to the greater amounts of runoff and soil loss from the plowed soil, the sediment phosphorus loss was also greater. The average sediment phosphorus loss from the plowed soil, at 13.0 mg/m^2, was significantly greater than the losses from the aerwayed and the aerwayed + subsoiled treatments, which averaged 2.8 and 2.6 mg/m^2 respectively (Table 4.4). Thus, sediment phosphorus loss was reduced 80% by using aerway tillage instead of the moldboard plow.

Soluble orthophosphate-P concentrations in the runoff were low for all treatments, with an overall average of 0.036 mg/L. The average soluble orthophosphate-P loss from the plowed treatment was 0.06 mg/m^2, while the aerwayed and aerwayed + tillage treatments both averaged 0.03 mg/m^2 (Table 4.4).

SUMMARY:

The combination of aerway tillage, with and without an additional subsoiling treatment, and a hairy vetch cover crop, resulted in significant reductions in runoff volume, sediment volume and sediment phosphorus loss, in comparison to moldboard plowing. However, the slope of the moldboard plots was significantly greater than the slope of the aerwayed plots, and may have affected runoff volumes. Soluble orthophosphate-P losses from all tillage treatments were very low.

4.5 THE EFFECT OF MANURE APPLICATION, TILLAGE, AND FALL COVER CROPS ON EROSION (Q. MARTIN FARM, NOV. 1989)

4.5.1 SITE DESCRIPTION

Liquid swine manure was applied at a rate of 75,000 L/ha and incorporated with two diskings, following harvest of a winter wheat crop on August 17, 1989. On some treatments, oilseed radish was seeded at 20 kg/ha to provide soil cover and to take up nutrients. The plots were either moldboard plowed (conventional tillage), chisel plowed (reduced tillage), or left untilled (zero till) in the fall. The site was located on the farm of Q. Martin, Woolwich Township, Waterloo County. Rainfall simulation was carried out November 6-10, 1989, after fall tillage.

A composite sample of the surface soil was not obtained from the site, but one taken from the same site the following May had a loam texture with a soil test phosphorus level of 18 mg/kg, a pH of 6.6 and an organic matter content of 2.8%.

4.5.2 STATISTICAL ANALYSES

Statistical analyses were conducted on data using analysis of variance (ANOVA); degrees of freedom for treatment effects were partitioned into single degree of freedom orthogonal comparisons. Significance was determined at $p \leq 0.10$.

4.5.3 RESULTS AND DISCUSSION

GROUND COVER AND SLOPE:

The amount of ground cover at the time of the rainfall simulations was dependent upon a combination of tillage and the use of oilseed radish as a cover crop (Table 4.5). The conventional tillage averaged 2% cover, and reduced tillage, 25%. The zero-till wheat stubble averaged 50% ground cover where oilseed radish was not grown and 84% cover where the radish was grown.

The average slope of the rainfall simulation plots at the site ranged from 2.8% to 8.4%, with an overall average of 6% (Table 4.5). The zero-till plot that received a summer manure application was located at the extreme south part of the field and had only a 2.8% slope. This treatment lowered the overall average of the zero-till treatments. As a result, the tillage comparison between conventional versus zero-till shows a significant difference with respect to slopes (Table 4.5). None of the other comparisons showed significant slope differences.

SOIL MOISTURE:

There were significant interactions of tillage, manure and cover crop with respect to soil moisture (Table 4.5). Air dried gravimetric soil moisture under zero-till (22.3%) and reduced

Table 4.5. Data from Rainfall Simulations Conducted on November 6-10, 1989, at the Farm of Q. Martin, Waterloo County. (154.8 mm/h intensity for 10 minutes)

Tillage	Manure/Cover	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)	Ortho P Loss (mg/m²)
Conventional	Summer Manure + Radish	6.9	3	19.8	0.32	4.0	2.55	0.02
	Summer Manure	6.0	3	21.5	0.92	7.4	4.85	0.04
	No Manure	7.5	1	21.4	1.45	8.9	5.89	0.07
Reduced	Summer Manure + Radish	5.2	24	22.5	0.32	5.0	3.73	0.01
	Summer Manure	8.4	30	22.0	1.40	11.4	8.69	0.02
	No Manure	6.4	22	21.5	0.23	2.3	1.58	0.01
Zero-Till	Summer Manure + Radish	5.7	84	19.6	0.34	0.7	0.65	0.01
	Summer Manure	2.8	48	24.5	0.18	2.5	1.69	0.01
	No Manure	5.7	52	22.8	0.21	2.5	1.61	0.01
Probability That the Difference Between Means of Specified Contrast is Zero								
Tillage		0.128	0.000	0.081	0.164	0.138	0.120	0.043
	Conventional vs. Reduced	0.919	0.000	0.086	0.463	0.838	0.890	0.041
	Conventional vs. Zero-till	0.072	0.000	0.035	0.063	0.071	0.086	0.022
Manure		0.772	0.008	0.015	0.319	0.325	0.270	0.538
	Summer Manure + Radish vs. Summer Manure	0.855	0.011	0.004	0.138	0.146	0.123	0.442
	Summer Manure vs. No Manure	0.493	0.621	0.229	0.541	0.325	0.246	0.757
Tillage x Manure		0.231	0.001	0.025	0.191	0.475	0.354	0.607

tillage (22.0%) was significantly higher than the average soil moisture of the conventionally tilled treatments (20.9%). The oilseed radish treatment had the lowest soil moisture under the conventional and zero-tillage treatments, but not the reduced tillage treatment. Overall, soil moisture was significantly lower under oilseed radish treatments in comparison to treatments where there was no oilseed radish.

RUNOFF VOLUME:

All of the runoff volumes were low, which was not expected given the moist soil conditions. Runoff volume was highly variable within many of the treatments (Figure 4.5), ranging from 0.02 L/m^2 up to 2.5 L/m^2 within the conventionally tilled, summer manure treatment.

Runoff volume from the conventional tillage treatments averaged 0.90 L/m^2, and was significantly greater than the average runoff from the zero-till treatments (0.24 L/m^2) (Table 4.5). Runoff volume from the reduced tillage treatments averaged 0.65 L/m^2 and was not significantly different from the volume generated by the conventional tillage treatment.

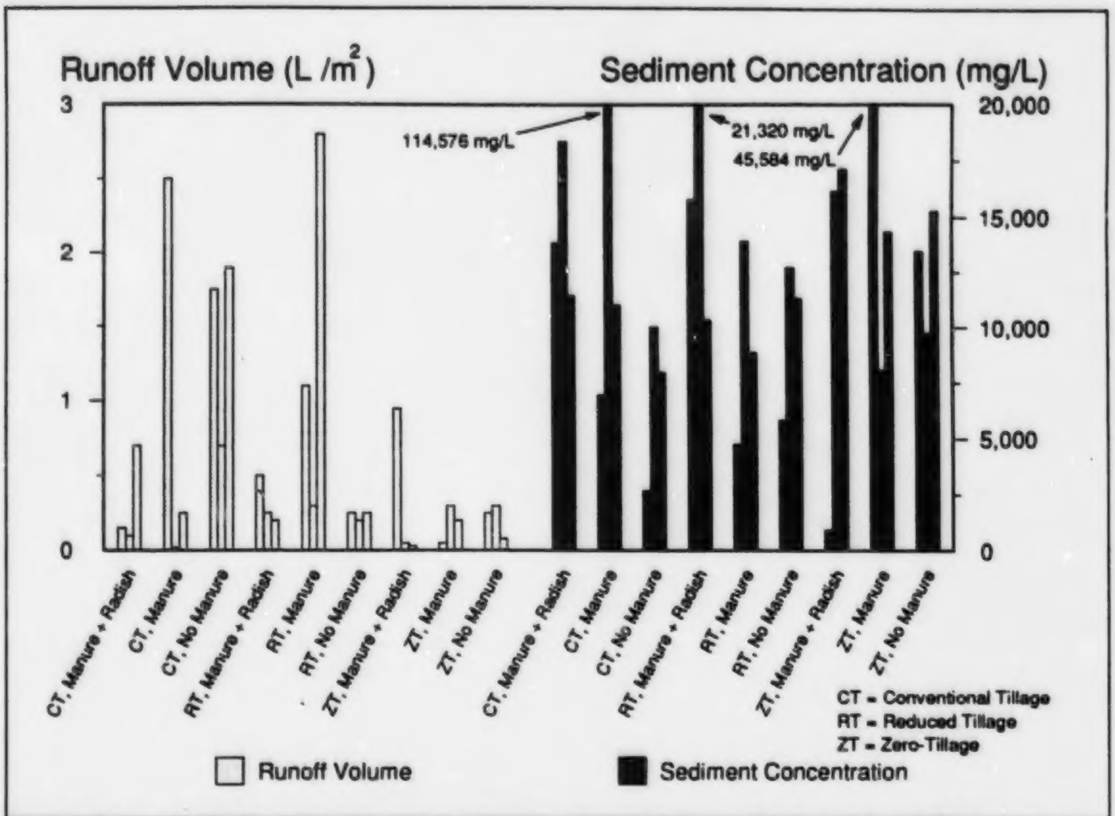

Figure 4.5. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the Q. Martin farm in Nov., 1989.

SOIL LOSS:

Sediment concentrations in the runoff were highly variable within some treatments (Figure 4.5). All of the repetitions on the zero-till treatments that had high sediment concentrations corresponded to low runoff volumes, thus soil loss from these repetitions, and the zero-tillage treatment in general, were low.

The least amount of soil loss, at 0.7 g/m^2, was from the zero-till, summer manure + radish treatment. Sediment losses from all of the zero tillage treatments averaged 1.9 g/m^2, and were significantly less than the 6.8 g/m^2 average sediment losses from the conventional tillage treatments (Table 4.5). The high residue cover and lack of recent soil disturbance on the zero-till treatments were likely responsible for the low sediment losses. Sediment losses from the reduced tillage treatments averaged 6.3 g/m^2, and were not significantly less than the losses from the conventional tillage treatment.

PHOSPHORUS LOSS:

Despite the manure applications and the varied degrees of soil mixing of the treatments, the concentrations of phosphorus associated with the sediment did not differ significantly, and averaged 0.72 mg P/kg sediment. Because the amount of soil loss was affected by treatment, the overall phosphorus loss from the plots was also related to tillage. Sediment phosphorus losses from the zero tillage treatments averaged 1.32 mg/m^2, and were significantly less than the average sediment phosphorus losses from the conventional tillage treatment (4.43 mg/m^2) (Table 4.5).

Loss of soluble orthophosphate-P was greatest for conventional tillage (0.04 mg/m^2). Soluble orthophosphate-P losses from the reduced tillage treatment (0.014 mg/m^2) and the zero-till treatment (0.010 mg/m^2) were significantly lower than the losses from the conventional tillage treatment (Table 4.5). All of the soluble orthophosphate-P losses were small and were dependent upon both the amount of runoff and the concentration of soluble orthophosphate in the runoff water. The concentrations of orthophosphate in the runoff were generally low, near the detection limit of the instrumentation (0.01 mg/L). However, statistically significant differences were evident between orthophosphorous concentrations in the conventional tillage (0.10 mg/L) and the reduced tillage (0.03 mg/L) but not between conventional and zero-till (0.08 mg/L).

SUMMARY:

Rainfall simulations were conducted on three different tillage systems (conventional, reduced and zero-till) with three different manure management treatments (manure + oilseed radish, manure, no manure). The tillage treatment had significant effects on the erosivity of the rainfall simulation plots.

The zero tillage treatment generated significantly less runoff and lost significantly less soil and sediment bound phosphorus than the conventional (fall moldboard plow) tillage treatment.

Hence, soil and phosphorus losses are minimized under conditions following winter wheat harvest where the soil surface is lightly cultivated to incorporate manure, with no further fall tillage. Summer manure applications did not increase sediment phosphorus or soluble orthophosphate losses under moldboard, chisel plow and zero-till tillage methods, with or without a cover crop of oilseed radish. The seeding of an oilseed radish crop provides greater fall cover relative to wheat residues alone, but does not contribute to further reductions in soil and phosphorus losses. Moldboard plow tillage in the fall increased soil and phosphorus losses on this sandy loam site relative to the system of no fall tillage.

5. Study Findings: Year 2 (1990 Field Season)

Rainfall simulations were conducted in May, June and November of 1990 at the farms of five TED research cooperators. The effects of cover crops, aeration tillage and manure management systems on runoff and erosion were investigated. At two of the farms, rainfall simulations were carried out before spring tillage, after planting and after harvest.

5.1 Erosion Control Resulting from Fall and Spring Killed Red Clover Using Chemical or Mechanical Methods (R.E. Thompson farm, May 1990)

5.1.1 Site Description

Red clover was established in winter wheat in August 1989 and was killed by chemical spray application (2,4-D, atrazine and oil), moldboard plowing or chisel plowing in either the fall of 1989 or spring of 1990. Rainfall simulation was used to test the effect of the residue cover left by the various kill methods on the amount of runoff, sediment and phosphorus losses.

The site was located on the farm of R.E. Thompson, Goderich Township, Huron County. Rainfall simulation was carried out May 23-24, 1990, a few days after the fields had been planted to corn. The average slope of the treatments ranged from 3% to 6.2%. The runoff collection troughs were oriented perpendicular to the direction of the slope. Tillage operations and corn planting had been conducted up and down the slope.

The composite sample of the surface soil at the site had a loam texture with a soil test phosphorus level of 30 mg/kg, a pH of 7.5 and an organic matter content of 3.6%.

5.1.2 Statistical Analyses

Statistical analyses were conducted on the data using analysis of variance (ANOVA); degrees of freedom for treatment effects were partitioned into single degree of freedom orthogonal comparisons. Significance was determined at $p \leq 0.10$.

5.1.3 Results and Discussion

Ground cover and Slope:

The treatments in this experiment varied widely in the amount of residue cover and the slope (Table 5.1). The residue cover of the fall and spring chemical killed plots averaged 46% and 61% respectively. Of the two chemically killed treatments, there was significantly more residue cover on the spring application. The residue cover of the fall and spring chemically killed treatments was significantly higher than the residue cover of the

mechanically killed treatments. The average residue cover of the fall chisel plow killed plot was 18%, significantly greater than the cover on the moldboard killed plots.

Table 5.1. Data from Rainfall Simulations Conducted on May 23-24, 1990, at the Farm of R.E. Thompson, Huron County. (154.8 mm/h intensity for 10 minutes)

Kill Type	Timing	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)
Chemical	Fall '89	3.0	46	23.1	5.6	16.5	23.6
Chemical	Spring '90	3.7	61	23.8	4.2	11.2	14.6
Moldboard	Fall '89	5.8	5	23.0	19.9	217.5	225.5
Moldboard	Spring '90	6.2	6	22.3	13.9	161.5	152.5
Chisel	Fall '89	4.2	18	19.6	13.1	107.9	134.0
Probability That the Difference Between Means of Specified Contrast is Zero							
Chemical vs. Mechanical		0.003	0.000	0.017	0.000	0.002	0.002
Chemical: Fall vs. Spring		0.437	0.075	0.476	0.603	0.928	0.873
Moldboard: Fall vs. Spring		0.694	0.928	0.516	0.043	0.343	0.216
Moldboard vs. Chisel		0.028	0.084	0.006	0.115	0.125	0.277

The field plots were oriented perpendicular to the slope of the field. Because of the experimental set-up, the mechanically killed plots (spring and fall moldboard and fall chisel) were located on slopes that were significantly steeper (average slope = 6%) than either the chemically killed plots (average slope = 3.4%) or the fall chisel killed plots (average slope = 4.2%) (Table 5.1). The slope difference between treatments may have influenced the rainfall simulation results.

SOIL MOISTURE:

At the time of the rainulator studies, the average gravimetric moisture of the soil was 22.4%. The lowest moisture content, 19.6%, was from the plots that had been chisel plowed in the fall (Table 5.1). Although the magnitude of the difference was not great, the plots where the red clover had been chemically killed had a significantly higher gravimetric moisture content than the mechanically killed plots. A fair amount of natural rainfall (74 mm) had fallen in the five days before the simulations were conducted. It is possible that more of this rainfall infiltrated the soils of the chemically killed plots (as occurred during subsequent rainfall simulations), thus wetting the soil profile of the chemically killed plots more thoroughly than the soils of the mechanically killed plots.

RUNOFF VOLUME:

The volume of runoff obtained from the rainfall simulations ranged from a low of 1.1 L/m^2 on one of the spring chemical kill repetitions to a high of 21.5 L/m^2 on one of the fall plowed repetitions (Figure 5.1). Runoff volumes were significantly less from the chemically killed (no-till) treatments than from the moldboard plow or chisel plow treatments (Table 5.1). The average amount of runoff from the two chemically killed treatments was 4.9 L/m^2, compared to an average of 15.6 L/m^2 from the mechanically killed treatments. There was no significant difference between the amount of runoff from the fall and spring chemically killed plots. This would indicate that no further protection against erosion was obtained from the additional residue cover on the spring killed treatment. Runoff from the spring moldboard killed plot was significantly less than from the fall moldboard killed plot.

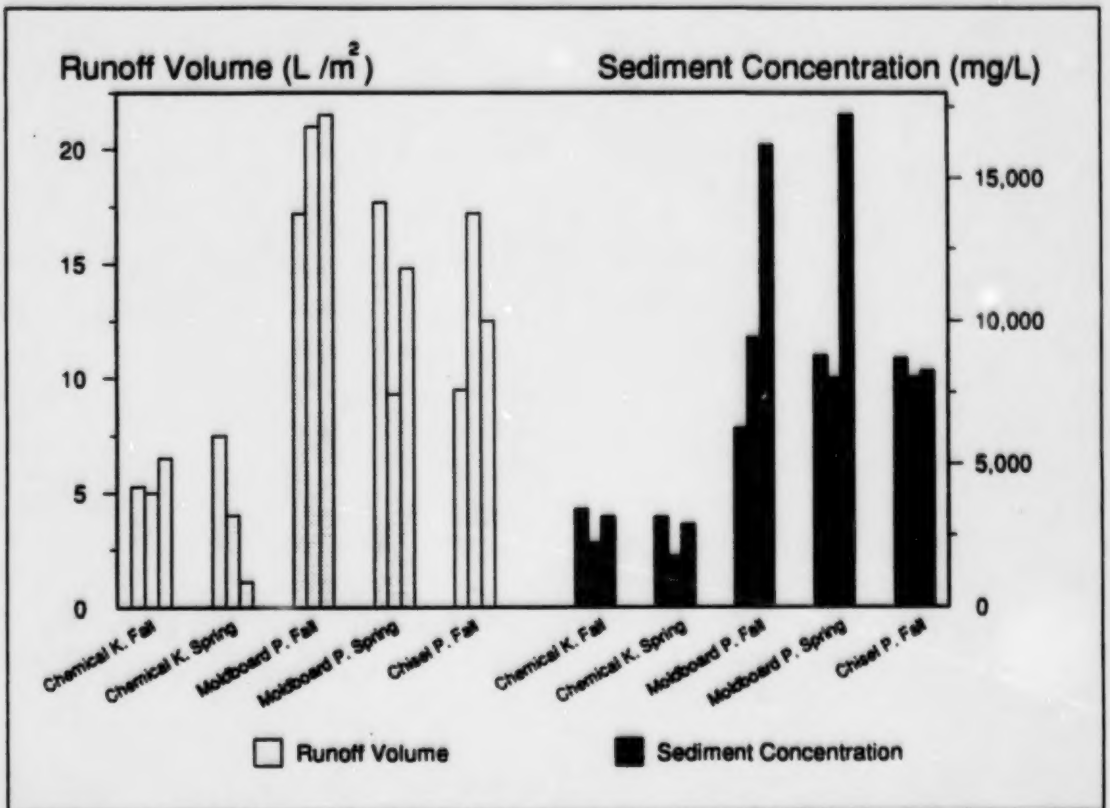

Figure 5.1. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the R.E. Thompson farm in May 1990.

The relative differences between runoff volumes of chemically killed versus moldboard plow killed red clover sites in 1990 are in agreement with the results obtained in 1989 TED rainfall simulations on similar treatments (W. Tebbut farm, May 1989).

SOIL LOSS:

The sediment concentration in the runoff from the chemically killed treatments was less than one third of what it was in the plowed treatments (Figure 5.1). When the runoff volumes were factored in, the amount of soil loss was significantly reduced when the red clover was killed using chemical means, as opposed to either the moldboard plow or the chisel plow (Table 5.1). Where the clover had been chemically killed, the average soil loss of 13.9 g/m^2 was significantly less than the average soil loss of 162.3 g/m^2 from the mechanically killed treatments.

PHOSPHORUS:

The concentration of phosphorus in the sediment from the runoff was slightly higher for the chemically killed treatments, averaging 1.4 g/kg, compared to 1.1 g/kg for the mechanically killed treatments. Since runoff and soil losses were greater from the mechanically killed treatments than the chemically killed treatments, the sediment phosphorus losses were also greater. Sediment bound phosphorus losses from the mechanically killed treatments were nine times greater than the losses from the plots where the red clover had been chemically killed (Table 5.1).

Soluble orthophosphate-P concentrations in the runoff were below the 0.01 mg/L level of detection for all but one replicate of the chisel plow treatment and one replicate of the spring chemically killed treatments.

SUMMARY:

When red clover is underseeded to wheat, its erosion control benefits the following spring are enhanced if it is killed by chemical spray application, rather than by tillage. The timing of the chemical application (fall or spring) did not significantly affect the performance of the red clover residue in controlling erosion. Thus, the 61% residue cover of the spring killed red clover was not significantly more effective than the 46% cover provided by the fall killed clover. Neither the chemically killed or the mechanically killed treatments generated runoff with measurable concentrations of soluble orthophosphate-P.

5.2 EFFECTS OF AERATION TILLAGE AND SUBSOILING ON RUNOFF, SEDIMENT AND PHOSPHORUS LOSSES (J. VAN DORP FARM, MAY, JUNE AND NOV. 1990)

5.2.1 SITE DESCRIPTION

Rainfall simulation was used to test the effect of tillage methods on the amount of runoff, sediment and phosphorus losses at the farm of J. Van Dorp, West Oxford Township, Oxford County. The composite sample of the surface soil at the site had a silt loam texture with a soil test phosphorus level of 27 mg/kg, a pH of 6.8 and an organic matter content of 3.4%.

In 1989, tests were conducted on three strips of soil which had been subjected to one of the following tillage methods: plowing, aerway and aerway plus subsoiling (Table 5.2). Three days before the September 1989 rainfall simulations, a moldboard plow was passed over part of the field, creating the "moldboard" treatment. On the same day, the aerway was passed over the aerway treatment, while no additional tillage was conducted on the other strip (it had been aerwayed and subsoiled in August). The tillage operations in mid September killed off most of the hairy vetch crop. The moldboard plow incorporated the hairy vetch, while the aerway left most of the residue on the surface. Results of the 1989 rainfall simulations were presented in Section 4.4 of this report (J. Van Dorp farm, Sep. 89).

The 1990 rainfall simulations were conducted on three separate occasions (Table 5.2). During planting, the aerway and planter are pulled in tandem, accomplishing both operations with a single pass.

Table 5.2. Timing of Rainfall Simulations and Planting, Harvest and Tillage Operations at the Farm of J. Van Dorp, Oxford County.

Timing	Upper Plot (Plowed)	Middle Plot (Aerwayed)	Lower Plot (Aerwayed + Subsoiled)
Jul. '89	Wheat Harvested	Wheat Harvested	Wheat Harvested
Aug. '89	Aerwayed and Hairy Vetch Planted	Aerwayed and Hairy Vetch Planted	Aerwayed + Subsoiled and Hairy Vetch Planted
Sep. '89	Moldboard Plowed *Rainfall Simulation*	Aerwayed *Rainfall Simulation*	*Rainfall Simulation*
May '90	*Rainfall Simulation* Corn Planted	*Rainfall Simulation* Aerwayed and Corn Planted	*Rainfall Simulation* Aerwayed and Corn Planted
Jun. '90	*Rainfall Simulation*	*Rainfall Simulation*	*Rainfall Simulation*
Nov. '90	Corn Harvested *Rainfall Simulation*	Corn Harvested Aerwayed *Rainfall Simulation*	Corn Harvested

The aerway was passed over the same plot as on previous occasions, three days prior to the post harvest November rainfall simulations. Measurements in November were confined to the plot that had been moldboard plowed in September 1989 and the plot that was aerwayed. Conditions were too wet for moldboard plowing, hence the plot that was formerly plowed would more appropriately be classified as "non-tilled". The plot that had been aerwayed and subsoiled in 1989 was not available for rainfall simulations in November. Rainfall simulations were conducted in November to assess whether any benefit was being derived through using the aerway on very wet soil.

In 1989 the slopes of the field plots had averaged 17% and 13% for the plowed and aerwayed treatments respectively. While the same strips of land were used in the May, June and November simulations as in September 1989, the average slopes ranged from 13.8% for the May 1990 plowed treatment to 8.8% for the aerwayed treatment in June 1990. The direction of tillage with the moldboard plow and the aerway was perpendicular to the slope of the land, such that the furrow of the plow left an area of exaggerated slope. The plow furrows had smoothed out over the winter, resulting in a decrease in the slope of the rainfall simulation plots. Crop rows were also oriented perpendicularly to the slope of the land.

5.2.2 Statistical Analyses

Statistical analyses were conducted on data using multiple comparisons (Duncan multiple-range). The Student's *t*-test was used for analyzing the November data, when only two treatments were tested. Significance was determined at $p \leq 0.10$.

5.2.3 Results and Discussion

Ground cover and slope:

The average ground cover and slopes of the three treatments during the May, June and November simulations are shown in Tables 5.3, 5.4 and 5.5 respectively. The plowed soil had an average residue cover of 10% in May, while the aerway and aerway + subsoiling plots averaged 57% and 93% residue cover respectively. Much of the residue on the aerway + subsoiling treatment was made up of hairy vetch that had not winter killed. In June, the aerway + subsoiling treatment still had significantly more residue cover than the other treatments (Table 5.4). Residue cover during the November 1990 simulations was primarily corn residue from the crop that had been harvested five days previously.

Table 5.3. Data from Rainfall Simulations Conducted on May 2-3, 1990 (before planting), at the Farm of J. Van Dorp, Oxford County.
(154.8 mm/h Intensity for 10 minutes)

Tillage	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)	Ortho P Loss (mg/m²)
Plowed (Sep. '89)	13.8 a	10 c	18.9 b	2.4 a	51.4 a	52.2 a	3.0 a
Aerwayed (Aug. & Sep. '89)	9.8 b	46 b	22.8 a	0.5 a	1.1 a	2.1 a	12.2 a
Aerwayed + Subsoiled (Aug. '89)	9.7 b	93 a	22.3 a	0.8 a	0.8 a	1.3 a	2.6 a

Means in the same column with different letters are significantly different at the 0.10 probability level

Table 5.4. Data from Rainfall Simulations Conducted on June 4, 1990 (after planting), at the Farm of J. Van Dorp, Oxford County.
(154.8 mm/h intensity for 10 minutes)

Tillage	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)
Plowed (Sep. '89)	11.0 a	2 b	22.7 b	25.9 a	413.4 a	405.3 a
Aerwayed (May '90) (Aerwayed Aug. & Sep.'89)	8.8 a	10 b	24.1 ab	12.4 b	83.5 b	86.7 b
Aerwayed (May '90) (Aerwayed + Subsoiled Aug. '89)	10.3 a	57 a	26.5 a	1.5 c	7.2 c	11.7 c

Means in the same column with different letters are significantly different at the 0.10 probability level

Table 5.5. Data from Rainfall Simulations Conducted on Nov. 6-7, 1990 (after corn harvest), at the Farm of J. Van Dorp, Oxford County.
(154.8 mm/h intensity for 10 minutes)

Tillage	Slope (%)	Residue Cover (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)
No-Till (Plowed Sep. '89)	10.0	92	30.7	4.5	4.4
Aerwayed	9.5	86	19.6	4.4	4.6

None of the means were significantly different at the 0.10 probability level

Soil Moisture:

At the time of the May simulations, the average air dried moisture content of the plowed soil was 18.9%, significantly lower than the soil moisture of the aerwayed and aerway + subsoiling treatments, which averaged 22.8% and 22.3% respectively (Table 5.3). In June the average gravimetric soil moisture contents were 22.7%, 24.1% and 26.5% for the plowed, aerwayed and aerway + subsoiling treatments respectively (Table 5.4). The moisture content of the plowed treatment was significantly greater than that of the aerway + subsoiled treatment. The higher moisture content of the aerwayed and subsoiled treatments may be the result of both improved infiltration into these soils or possibly the greater amount of residue cover on these treatments prevented the soil below from drying as much as the plowed treatment.

The November simulations were carried out on saturated soil, as approximately 50 mm of rain had fallen two days before the field work. Due to technical problems, data on gravimetric soil moisture contents are not available for the November simulations.

RUNOFF VOLUME:

In May, June and November, runoff volume was consistently higher from the plot that was plowed in 1989 (Tables 5.3, 5.4 and 5.5). In May, the soil of two of the rainfall simulation repetitions on the plowed treatment had extensive surface cracks. These two rainfall plots produced much less runoff (average of 0.15 L/m^2) compared to the plot without cracks which produced 7.0 L/m^2 of runoff (Figure 5.2). As a result of the high variability between replicates on the plowed treatment (standard deviation = 4.0 for runoff volume), none of the averages of runoff volume, soil loss or sediment phosphorus loss from the plowed treatment (Table 5.3) were significantly different from the other two treatments.

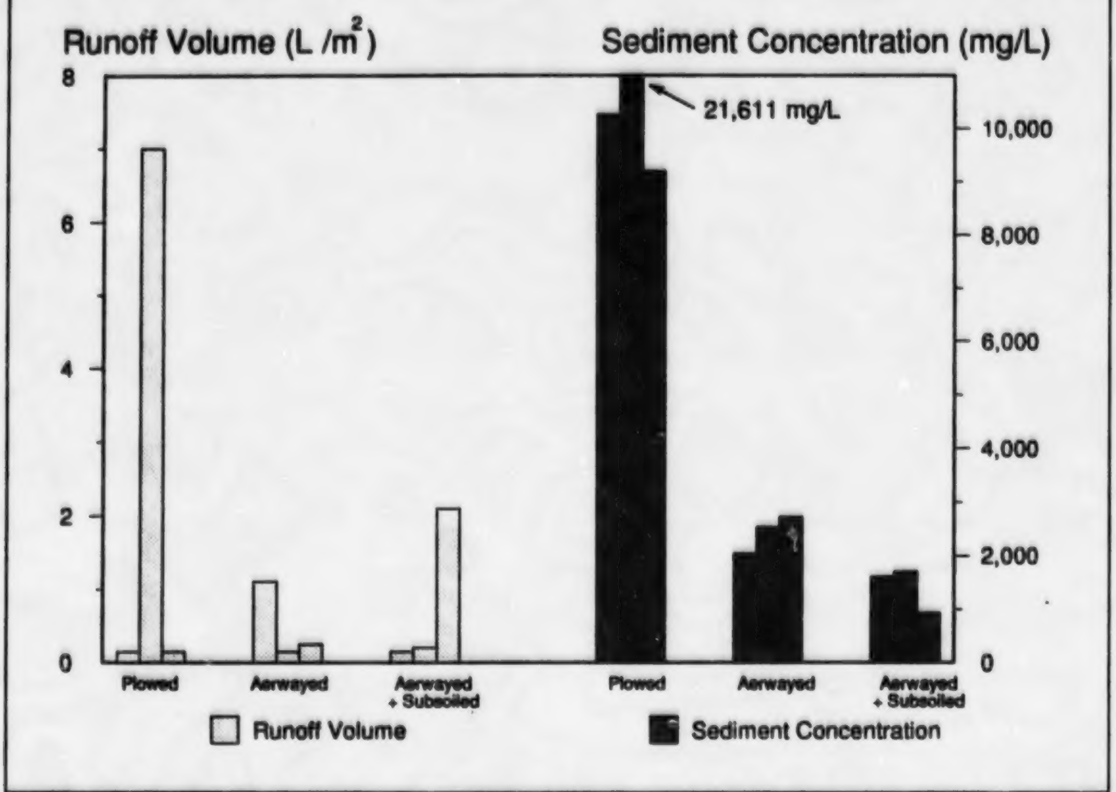

Figure 5.2. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the J. Van Dorp farm in May, 1990.

In June, soil cracks were not evident on any of the treatments, and runoff volumes within each treatment were fairly uniform (Figure 5.3). Runoff averaged 25.9 L/m^2 from the plowed treatment, 12.4 L/m^2 from the aerwayed treatment and 1.5 L/m^2 from the aerwayed + subsoiling treatment (Table 5.4). Runoff volumes from each of the three treatments were significantly different in June.

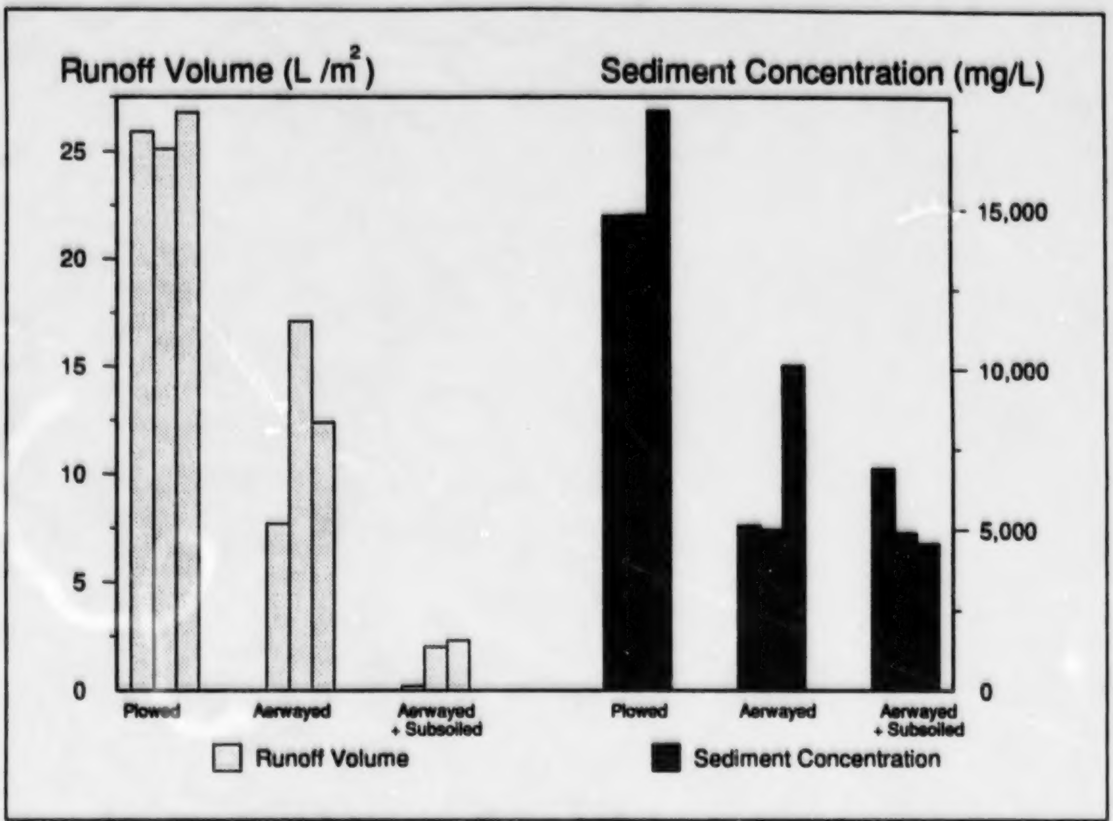

Figure 5.3. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the J. Van Dorp farm in June, 1990.

In November, average runoff volumes were 36% less from the aerwayed treatment than from the plot that had been plowed in September 1989. However, as shown in Figure 5.3, one of the replicates of the aerwayed treatment yielded very little runoff, thus lowering the overall average. The average runoff volumes from the aerwayed and plowed treatments were not significantly different ($p \leq 0.10$) (Table 5.5).

SOIL LOSS:

More sediment was lost from the plowed soil than from the aerway tillage treatments for the May and June simulations (Tables 5.3 and 5.4). The aerwayed + subsoiled treatment had the lowest soil losses, possibly due its greater amount of surface cover. The differences were significant for the June simulations. As discussed in the section on runoff volumes, surface cracks on two of the plowed plots in May may have captured much of the rainwater. Loss of runoff to soil cracks lowered the average values for both runoff volume and sediment loss from the plowed treatment.

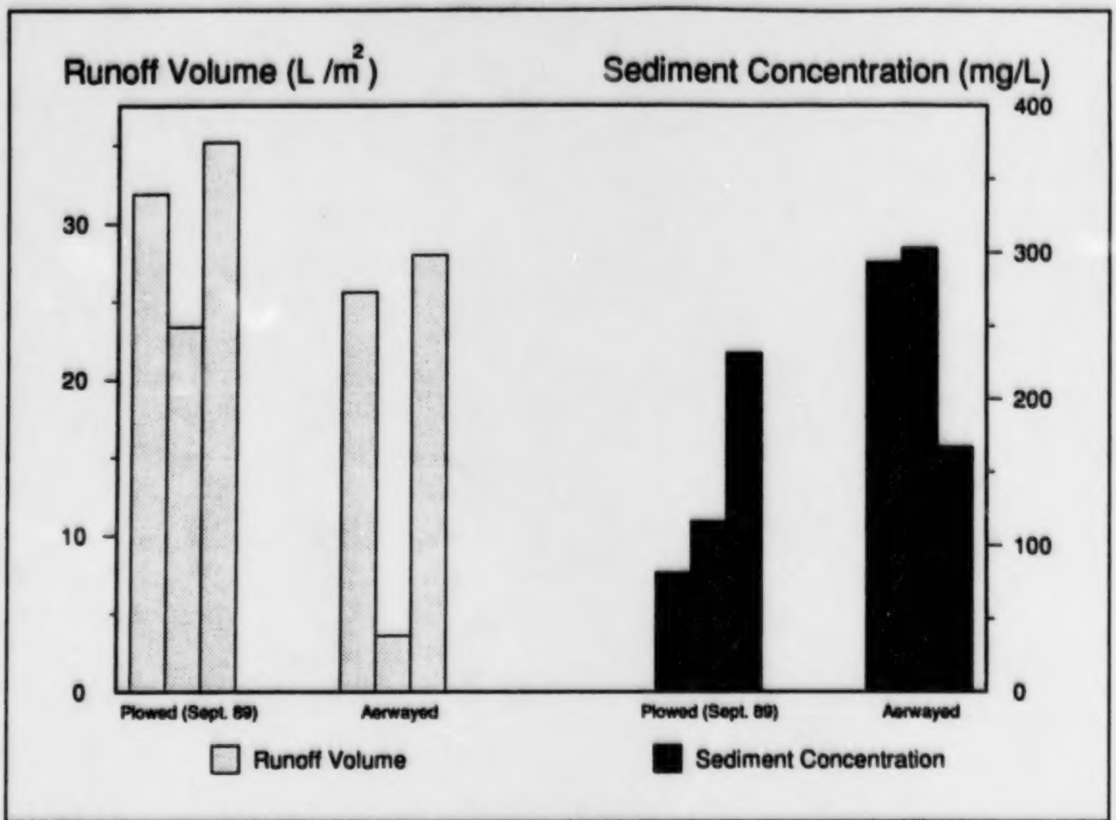

Figure 5.4. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the J. Van Dorp farm in Nov., 1990.

In both the May and June rainfall simulations, the sediment concentration of the runoff from the plowed treatment was significantly higher than that of the aerwayed and aerwayed + subsoiled treatments ($p \leq 0.025$). Figures 5.2 and 5.3 illustrate the large difference in sediment concentrations. The minimal amount of residue cover on the plowed treatment likely contributed to the large amount of sediment in the runoff from that treatment. In November, runoff water from the non-tilled treatment (plowed in Sep. 1989) had a lower sediment content than runoff from the aerwayed treatment (Figure 5.4), possibly due to the recent soil disturbance by the aerway.

PHOSPHORUS LOSS:

Phosphorus losses in May, June and November simulations from the various treatments are shown in Tables 5.3 through 5.5. More sediment bound phosphorus was lost from the plowed treatment than from the other two during the May and June simulations. In June, sediment phosphorus losses were significantly different between treatments and averaged

405.3, 86.7 and 11.7 mg/m^2 for the plowed, aerwayed and aerwayed + subsoiled treatments respectively (Table 5.4).

The large differences in sediment phosphorus loss between treatments in May and June indicate that aerway tillage in combination with hairy vetch residue can be an effective practice for soil and phosphorus conservation. The June results show reductions in phosphorus loss of 79% compared to fall plowing. Where the previous year's hairy vetch crop had not been killed by the aerway, the average reduction in phosphorus loss was 97% compared to moldboard plowing. When viewing the results from the series of rainfall simulations at this site it must be noted that the slopes of the plowed treatment plots were consistently greater than for the aerway and aerway + subsoiling treatments. The greater slope of the plowed treatment could have increased its susceptibility to runoff.

Soluble orthophosphate-P concentrations in the runoff in the May simulations averaged between 4.5 and 5.9 mg/L for all treatments. While the aerwayed treatment had the highest losses of orthophosphate-P, its losses were not significantly greater than those from the plowed or aerwayed + subsoiled treatments ($p \leq 0.10$). Only one of the orthophosphate-P concentrations in the June samples and none in November were above the 0.01 mg/L detection limit.

SUMMARY:
After spring planting, the aerway tillage system resulted in a 50% decrease in runoff volume and an almost 80% reduction in sediment and sediment bound phosphorus loss compared to fall moldboard plowing. When a subsoiling implement had been used in addition to the aerway, and a hairy vetch cover crop was allowed to overwinter, even greater reductions in runoff, soil and phosphorus loss were observed. The results of simulations conducted before planting support those from after planting, but differences were not significant. The November rainfall simulations were hampered by very wet soil conditions and did not provide any significant results.

5.3 EROSION CONTROL RESULTING FROM COVER CROPS IN AN AERATION TILLAGE SYSTEM (M. KLYNSTRA FARM, MAY, JUNE AND NOV. 1990)

5.3.1 SITE DESCRIPTION

Rainfall simulation was used to test the effect of cover crops in an aeration tillage system on the amount of runoff, sediment and phosphorus losses at the farm of M. Klynstra, West Oxford Township, Oxford County.

Tests were conducted on four strips of soil which had been planted with winter wheat and one of the following cover crops in 1989: fall planted hairy vetch, oilseed radish, rye and red

clover. The rye cover crop was considered to be the standard management practice. In 1990, all of the treatments were planted in corn. The rye and oilseed radish treatments were broadcast seeded with oats in late July of 1990.

The 1990 rainfall simulations were conducted on three separate occasions. The first occurred in early May, before planting. A second series of simulations was conducted in June, after the treatments had been chemically killed, undergone secondary tillage (with the aerway tool) and been planted to corn. The final series of simulations was conducted in mid November, immediately after corn harvest.

The early May simulations were conducted at the east (upper) end of the field plots to take advantage of the greater slopes (5.5% to 6.5%) in that region. However, access to that part of the field was not possible in either June or November due to wet soil conditions. Therefore, the latter two series of simulations were conducted on the west (lower) part of the field, within 30 metres of the laneway. Slopes in this region ranged from 2% to 4.5%. The direction of the crop rows for all of the treatments was up and down the slope.

Soil samples from both the eastern and western ends of the field were identified as silt loams, with soil test phosphorus levels of 21 mg/kg and 20 mg/kg and organic matter content of 3.5% and 3.1% respectively. The pH of the soil at both locations was 6.5.

5.3.2 Statistical Analyses

Statistical analyses were conducted on data using multiple comparisons (Duncan multiple-range). Significance was determined at $p \leq 0.10$.

5.3.3 Results and Discussion

Ground cover and slope:

The residue cover and slope of the various treatments at the three times of measurement are shown in Tables 5.6 to 5.8. In May, the hairy vetch, rye and red clover cover crops were providing a dense surface cover. There were many weeds in the rye and red clover treatments. The oilseed radish crop had winter killed and the amount of residue was significantly less (at $p \leq 0.10$) than the other treatments in May.

The spray application (atrazine + oil) in mid-May killed all of the rye but only killed about 50% of the hairy vetch and red clover crops. As a result, both the hairy vetch and the red clover treatments had significantly more residue cover than the rye treatment, which, in turn, had significantly more residue cover than the oilseed radish treatment (Table 5.7). All of the treatments were aerwayed two weeks before the June rainfall simulations. In November, the residue cover on all of the treatments was primarily corn residue.

Table 5.6. Data from Rainfall Simulations Conducted on May 7-9, 1990 (before planting), at the Farm of M. Klynstra, Oxford County.
(154.8 mm/h intensity for 10 minutes)

Cover Crop	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)
Hairy Vetch	6.5 a	97 a	24.4 b	0.10 a	1.3 a	1.4 a
Oilseed Radish	6.3 a	65 b	28.5 a	0.10 a	0.7 a	0.9 a
Rye	6.2 a	93 a	31.3 a	0.05 a	0.2 a	0.2 a
Red Clover	5.5 a	98 a	27.8 ab	0.07 a	0.2 a	0.3 a

Means in the same column with different letters are significantly different at the 0.10 probability level

Table 5.7. Data from Rainfall Simulations Conducted on June 5-6, 1990 (after planting), at the Farm of M. Klynstra, Oxford County.
(154.8 mm/h intensity for 10 minutes)

Cover Crop	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Hairy Vetch	2.8 a	58 a	26.9 ab	2.2 b	6.3 b	6.8 b	< 0.2 b
Oilseed Radish	2.0 a	23 c	25.9 ab	7.6 a	61.5 a	63.6 a	< 0.8 b
Rye	3.8 a	39 b	27.2 ab	4.2 ab	30.6 ab	41.1 ab	3.7 a
Red Clover	4.3 a	57 a	28.3 ab	8.8 a	28.1 ab	40.9 ab	5.3 a

Means in the same column with different letters are significantly different at the 0.10 probability level

Table 5.8. Data from Rainfall Simulations Conducted on Nov. 20-21, 1990 (after corn harvest), at the Farm of M. Klynstra, Oxford County.
(154.8 mm/h intensity for 10 minutes)

Cover Crop	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Hairy Vetch	3.5 a	79 a	19.0 a	12.2 b	1.2 b	1.1 b	< 0.5 b
Oilseed Radish	3.8 a	63 b	23.2 a	17.6 ab	4.8 b	5.2 b	< 1.7 b
Rye	4.5 a	78 a	24.5 a	15.8 ab	3.9 b	4.1 b	5.9 ab
Red Clover	4.0 a	66 ab	20.8 a	23.7 a	14.1 a	15.6 a	18.0 a

Means in the same column with different letters are significantly different at the 0.10 probability level

SOIL MOISTURE:

At the time of the May simulations, the average air dried moisture content of the soil ranged from 24.4% for the hairy vetch treatment to 31.3% for the rye treatment (Table 5.6). The hairy vetch treatment had a significantly lower soil moisture content than the oilseed radish and rye treatments.

For the June and November rainfall simulations the soil had an average oven dried gravimetric moisture content of 27% and 21.9% respectively. The November simulations were carried out on soil that was freezing overnight and thawing by mid-morning.

RUNOFF VOLUME:

Runoff volumes obtained from the different treatments in May, June and November are shown in Tables 5.6, 5.7 and 5.8. In May, runoff was very low from all treatments, ranging from no flow on some plots to a maximum of 0.3 L/m^2 on one of the hairy vetch plots. The runoff and sediment concentration data for the May 1990 rainfall simulations have not been presented in a separate figure. All of the treatments were providing excellent erosion control. However, since no appreciable runoff was obtained, it was not possible to rank the treatments in terms of effectiveness.

In June, runoff volumes were highly variable for all but the red clover treatment (Figure 5.5), which yielded the most runoff, with an average of 8.8 L/m^2 (Table 5.7). Both the red clover and the oilseed radish treatments generated significantly more runoff than the hairy vetch treatment in June.

In November, runoff volumes within treatments were all highly variable (Figure 5.6), with the red clover treatment producing the most amount of runoff. Runoff from the red clover treatment averaged 23.7 L/m^2, and was significantly greater than the 12.2 L/m^2 average runoff from the hairy vetch treatment (Table 5.8). The average runoff volume from the red clover treatment plots was 92% of the total amount of water (25.8 L/m^2) theoretically applied to each plot. As shown in Figure 5.6, one of the red clover replicates yielded an excessive volume of runoff (a total of 30.3 L/m^2). The soils were very moist at the time of the November simulations. Additional runoff could have inadvertently entered the runoff collection trough through seepage around the sides of the plot.

SOIL LOSS:

Sediment losses from the different treatments for the May, June and November simulations are shown in Tables 5.6 to 5.8. In June, the within treatment concentration of sediment in the runoff was highly variable, particularly for the hairy vetch treatment (Figure 5.5). The average soil loss from the oilseed radish treatment (61.5 g/m^2) was significantly greater than corresponding losses from the hairy vetch treatment (6.3 g/m^2) (Table 5.7).

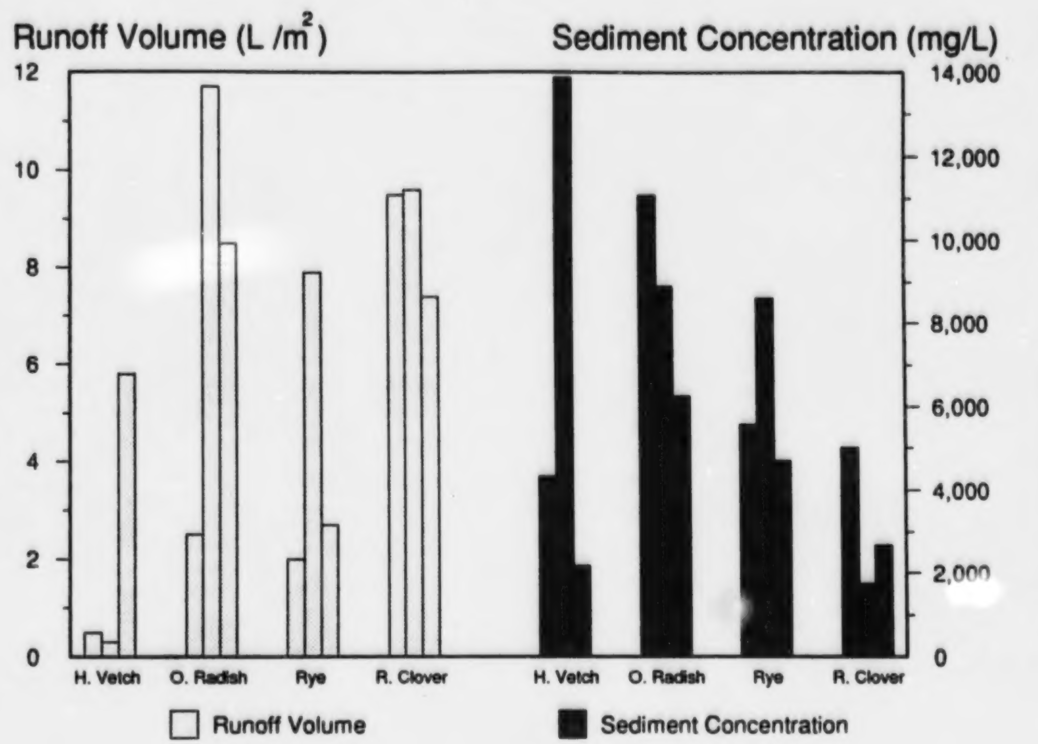

Figure 5.5. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the M. Klynstra farm in June, 1990.

In November, the concentration of sediment in the runoff was more uniform within individual treatments (Figure 5.6). Soil loss from the red clover treatment was significantly greater at the 0.10 level than that from the hairy vetch, rye and oilseed radish treatments (Table 5.8). High sediment losses from the red clover treatment in November were the result of more runoff and an average runoff sediment concentration (570 mg/L) that was over twice that from any of the other treatments. The hairy vetch treatment had a fair amount of weed growth (quack grass) along with the corn residue. This could have been a factor in the lower sediment concentration (121 mg/L) in the runoff from the hairy vetch plots.

PHOSPHORUS LOSS:

Total phosphorus losses from the different treatments in the May, June and November rainfall simulations are shown in Tables 5.6, 5.7 and 5.8. The 6.8 mg/m^2 average phosphorus loss from the hairy vetch treatment was significantly less than the 63.6 mg/m^2 average loss from the oilseed radish treatment (Table 5.7) at the 0.10 level. In November,

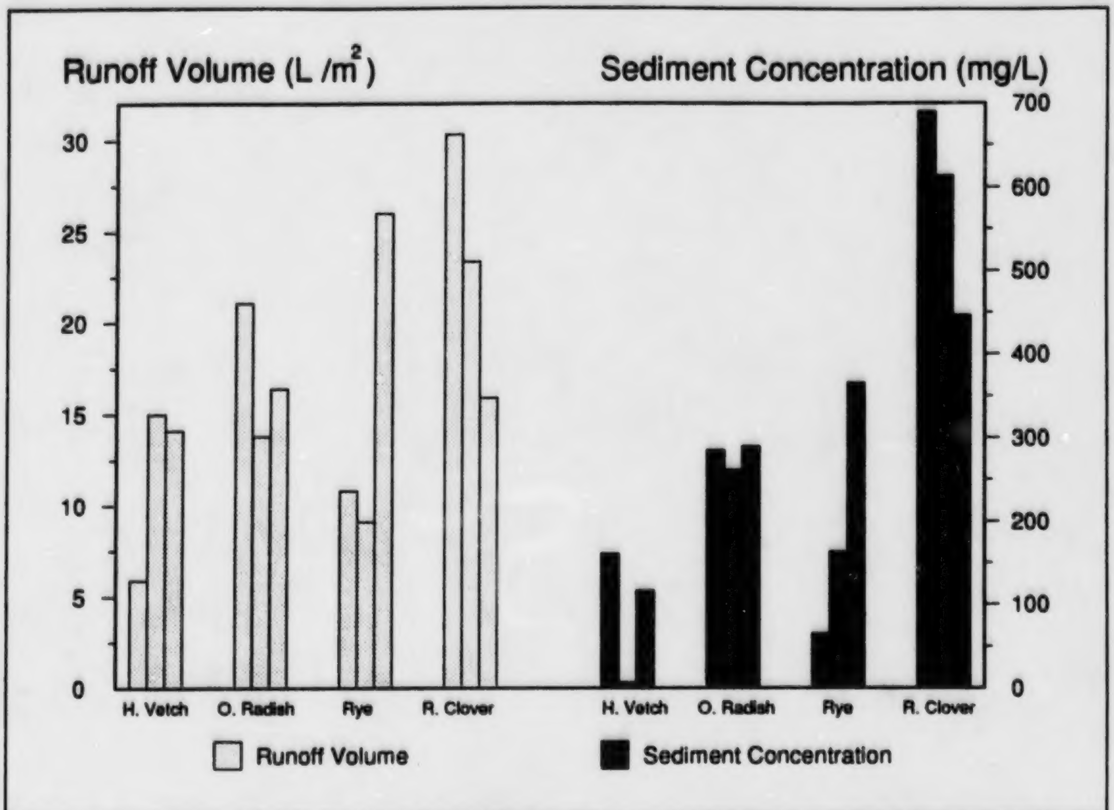

Figure 5.6. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the M. Klynstra farm in Nov., 1990.

the red clover treatment lost significantly more total phosphorus than the other treatments since it generated more runoff with a higher sediment concentration.

Concentrations of soluble orthophosphate-P in the runoff were below the 0.01 mg/L level of detection for all treatments in the May simulations. In June and November, orthophosphate-P was detected in the runoff from the rye and red clover treatments (Tables 5.7 and 5.8). For comparative purposes, treatments which had no detectable amount of orthophosphate-P in the runoff were assigned a concentration of 0.01 mg/L. Values of orthophosphate-P loss which resulted from this method are preceded by an inequality sign ("<") in Tables 5.7 and 5.8.

The maximum concentration of soluble orthophosphate-P was 0.31 mg/L. It was measured in one of the repetitions from the rye treatment in June. The loss of soluble orthophosphate-P was highest from the red clover treatment, averaging 5.3 and 18.0 mg/m^2 in June and November respectively. In June, both the red clover and the rye treatments had significantly

greater soluble orthophosphate-P losses than the hairy vetch and oilseed radish treatments (Table 5.7). In November, the red clover treatment had significantly greater soluble orthophosphate-P losses than the hairy vetch and oilseed radish treatments (Table 5.8).

SUMMARY:

Rainfall simulations were conducted in May, June and November to compare the erosion control benefits provided by residue from a winter cover crop of hairy vetch, oilseed radish, rye or red clover. Plots having red clover and oilseed radish residue cover tended to generate more runoff and lose more sediment and sediment bound phosphorus than where the previous cover crop was hairy vetch or rye. The highest losses of soluble orthophosphate-P were from the red clover and the rye treatments. Hairy vetch appeared to provide the best and longest lasting erosion control benefits of the four cover crops tested.

5.4 EFFECTS OF AERATION TILLAGE ON RUNOFF, SEDIMENT AND PHOSPHORUS LOSSES (J. GERBER FARM, MAY 1990)

5.4.1 SITE DESCRIPTION

Rainfall simulation was used to test the effect of aeration tillage on the amount of runoff, sediment and phosphorus losses at the farm of J. Gerber, located in Wellesley Township, Waterloo County. One of the treatments had been aerwayed once in the fall and twice in the spring. The standard management treatment had been moldboard plowed in the fall and cultivated twice in the spring. Both fields had been planted in corn in 1989 and neither field had a cover crop. Tests were conducted on May 25th, 1990, two weeks after corn planting.

The composite sample of the surface soil at the site had a clay loam texture with a soil test phosphorus level of 7 mg/kg, a pH of 6.7 and an organic matter content of 3.7%.

Tillage operations and crop seeding had been conducted up and down slope. However, in some areas the rows were oriented at roughly a 45° angle to the slope, due to undulations in the field.

5.4.2 STATISTICAL ANALYSES

Statistical analyses were conducted on the data from the two tillage systems using the Student's *t*-test. Significance was determined at $p \leq 0.10$.

5.4.3 Results and Discussion

Ground cover and slope:

The average residue cover on the standard management and aeration tillage treatments was 10 and 15% respectively (Table 5.9). The aeration tillage treatment had a rougher surface and more soil cracks than the standard treatment.

Table 5.9. Data from Rainfall Simulations Conducted on May 25, 1990, at the Farm of J. Gerber, Waterloo County. (154.8 mm/h intensity for 10 minutes)

Tillage	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)
Plowed	3.2 a	10 b	26.0 a	7.7 a	60.8 a	56.2 a
Aerway	3.0 a	15 a	23.3 b	3.5 a	24.7 a	20.3 a

Means in the same column with different letters are significantly different at the 0.10 probability level

The slopes of the standard and aeration tillage treatments averaged 3.1%.

Soil Moisture:

The 26.0% average gravimetric soil moisture content of the standard treatment was significantly greater than the 23.3% soil moisture content of the aerwayed treatment.

Runoff Volume and Soil Loss:

Runoff volumes within each treatment were highly variable (Figure 5.7), while the concentration of sediment in the runoff remained fairly uniform. One repetition on the plowed treatment yielded over 13 L/m^2, which raised the treatment average. Average runoff volume and sediment losses from the plowed treatment and the aeration tillage treatments are shown in Table 5.9. Although the difference was not statistically significant, the average runoff and sediment loss from the plowed treatment was more than twice that of the aeration tillage treatment.

Phosphorus Loss:

Sediment bound phosphorus loss from the two treatments is shown in Table 5.9. The differences were not significantly different, but the plowed treatment averaged almost three times as much sediment phosphorus loss as the aeration tillage treatment.

Soluble orthophosphate-P concentrations in the runoff from both treatments were below the 0.01 mg/L level of detection.

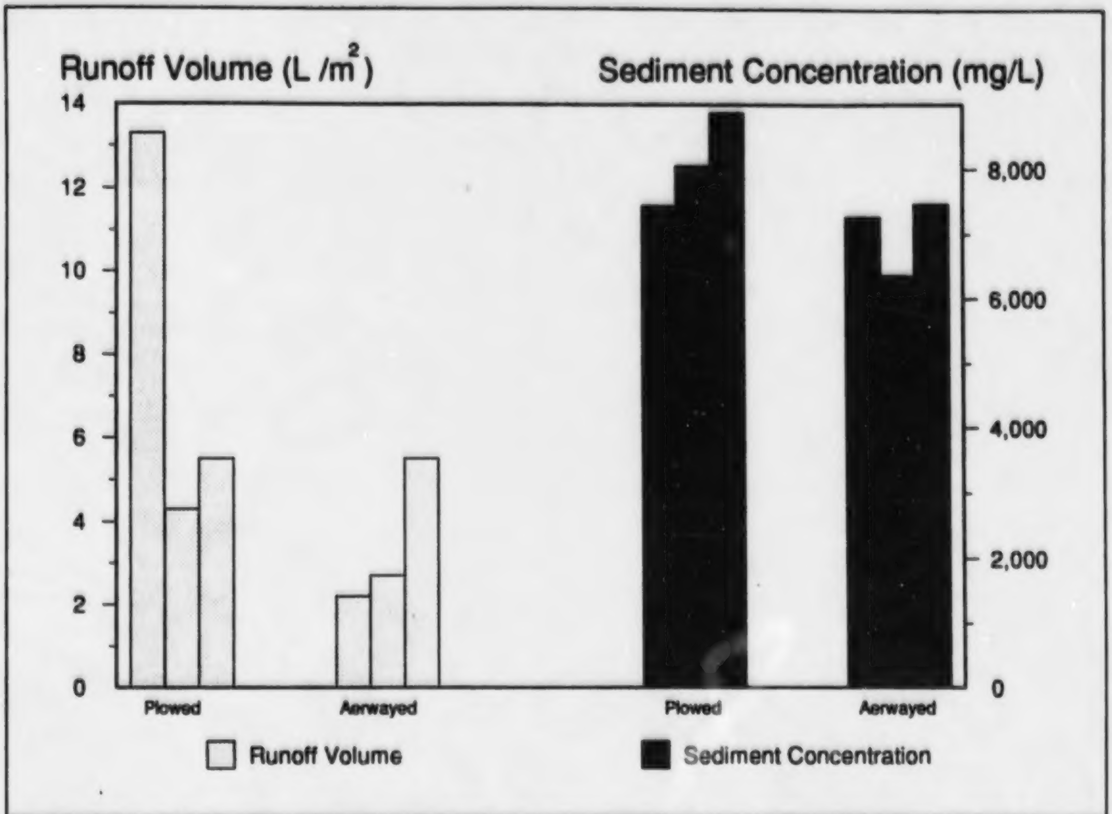

Figure 5.7. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the J. Gerber farm in May, 1990.

SUMMARY:

On a clay loam soil, the aerwayed treatment tended to provide better erosion control than the fall plowed treatment, although the runoff volumes and the soil and sediment phosphorus losses from the two treatments were not significantly different.

5.5 THE EFFECT OF TILLAGE SYSTEM, TIMING OF MANURE APPLICATION, AND FALL COVER CROPS ON RUNOFF, SEDIMENT AND PHOSPHORUS LOSSES (Q. MARTIN FARM, MAY 1990)

5.5.1 SITE DESCRIPTION

Rainfall simulation was used to test the effect of four different tillage systems in conjunction with spring and summer manure applications and a fall cover crop on the amount of runoff, sediment and phosphorus losses at the farm of Q. Martin, Woolwich Township, Waterloo County.

The tillage systems tested were: conventional tillage (fall moldboard plow), reduced tillage (fall chisel plow), zero-till and spring tillage with the aerway (aeration tillage) tool. The summer manure treatment was applied in August 1989 following winter wheat harvest. Manure was incorporated with a disc. Some of the summer manure treatments had a fall oilseed radish crop to provide soil cover and to take up nutrients. Some of the treatments received fall tillage.

Liquid swine manure was applied to the spring manure plots on May 8th, 1990 at a rate of 75,000 L/ha. On the conventional and reduced tillage treatments, the manure was incorporated with a cultivator. The manure was incorporated with an aerway on the aerwayed plots. No manure incorporation occurred on the zero-till plots. Corn was planted on May 10, and rainfall simulation was carried out on May 28-31. The rainfall simulations were carried out on the same field plots as in the previous year (Q. Martin farm, Nov. 1989) with the addition of the spring aeration tillage and spring manure application treatments. A "no manure" treatment was not available for testing.

The composite sample of the surface soil at the site had a loam texture with a soil test phosphorus level of 18 mg/kg, a pH of 6.6 and an organic matter content of 2.8%.

5.5.2 Statistical Analyses

Statistical analyses were conducted on data using analysis of variance (ANOVA). Significance was determined at $p \leq 0.10$.

5.5.3 Results and Discussion

Ground cover and Slope:

The amount of ground cover at the time of the rainfall simulation was influenced by both tillage and manure/oilseed radish treatment (Table 5.10).

Averaged by tillage treatment, the highest percentage residue (28%) was on the zero-till treatment, followed by the spring aerway treatment at 21%, reduced (fall chisel) at 15% and the conventional (fall moldboard) treatment at 4.2%. The residue cover on the zero-till, spring aerway and reduced tillage treatments was significantly higher than the cover on the conventional tillage treatment.

The oilseed radish crop that had provided a large amount of residue cover in November 1989 had winter killed and added little to the residue cover in May 1990. Within all tillage categories except the conventional, plots that had an oilseed radish crop the previous fall had the least amount of residue cover in May. The highest average residue cover (20%) was found on the spring manure treatment, followed by the summer manure treatment (18%) and the summer manure + radish treatment (13%).

Table 5.10. Data from Rainfall Simulations Conducted on May 28-31, 1990, at the Farm of Q. Martin, Waterloo County. (154.8 mm/h Intensity for 10 minutes)

Tillage	Manure/Cover	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)
Conventional	Summer Manure + Radish	2.8	7	16.5	8.6	100.7	60.1
	Summer Manure	3.0	2	17.2	11.5	245.5	159.5
	Spring Manure	2.8	4	16.7	10.3	124.4	79.3
Reduced	Summer Manure + Radish	3.3	8	17.0	9.3	85.7	54.0
	Summer Manure	3.3	17	17.4	7.7	86.2	65.3
	Spring Manure	2.7	20	16.3	6.6	61.6	39.0
Zero-Till	Summer Manure + Radish	3.5	25	15.6	8.3	106.4	65.5
	Summer Manure	2.5	25	16.0	4.5	53.6	32.3
	Spring Manure	2.5	34	18.7	1.6	10.7	6.8
Spring Aerway	Summer Manure + Radish	3.4	13	16.8	7.0	87.1	53.8
	Summer Manure	3.0	27	15.9	4.3	35.6	22.9
	Spring Manure	3.2	23	22.7	4.4	37.7	26.8
Probability That the Difference Between Means of Specified Contrast is Zero							
Tillage		0.417	0.000	0.538	0.002	0.006	0.009
	Conventional vs. Reduced	0.340	0.000	0.903	0.109	0.013	0.026
	Conventional vs. Zero-till	0.827	0.000	0.927	0.001	0.002	0.003
	Conventional vs. Aerway	0.244	0.000	0.236	0.001	0.002	0.003
Manure		0.121	0.015	0.046	0.109	0.179	0.187
	Summer Manure + Radish vs. Summer Manure	0.169	0.052	0.833	0.281	0.691	0.501
	Summer Manure + Radish vs. Spring Manure	0.046	0.005	0.025	0.037	0.166	0.245
Tillage x Manure		0.447	0.048	0.049	0.289	0.143	0.154

The slopes at the site averaged 3% in May 1990, compared to 6% on the same field plots in November 1989. It is likely that fall tillage had created exaggerated slope conditions on the micro scale which were reflected in the November slope measurements but were smoothed out over the winter and spring. The 3% slope of the manured zero-till plot did not change between November 1989 and May 1990, possibly because the un-tilled surface had less microtopography in November than the other treatments.

SOIL MOISTURE:

At the time of the rainfall simulations, the average soil moisture of the treatments ranged from a high of 22.7% on the aerway + spring manure application treatment to a low of

15.6% on the zero-till treatment that had a manure application the previous summer and a fall oilseed radish crop.

There was no effect on soil moisture due to tillage. Averaged by manure treatment, the average soil moisture of the treatments where manure was applied in spring (18.0%) was significantly greater than the soil moisture of the summer manure + radish treatment (16.5%) and the summer manure (no radish) treatment (16.6%) at $p \leq 0.10$. The reason for higher moisture contents on the spring manured plots is not clear. The site was thoroughly wetted by periods of natural rainfall in the three weeks between the spring manure application and the rainfall simulations. Thus, the liquid content of the manure should not have contributed to the greater amount of moisture in the spring manured plots.

RUNOFF VOLUME:

Most of the runoff volumes obtained from the replicates within each treatment were fairly uniform, with some exceptions (e.g. zero-till, summer manure + oilseed radish) (Figure 5.8a). The average runoff volumes from the different tillage and manure treatments are shown in Table 5.10. Runoff volume was more strongly affected by tillage than by manure/oilseed radish treatment.

Analysis of the data according to tillage showed that the conventional tillage treatment generated the greatest amount of runoff (10.1 L/m^2), followed by the reduced tillage treatment (7.9 L/m^2), the aerway tillage treatment (5.2 L/m^2) and the zero-till treatment (4.8 L/m^2). Both the zero-till and the aerway tillage treatments produced significantly less runoff than the conventional and reduced tillage treatments ($p \leq 0.10$). The volume of runoff from the reduced tillage treatments was not significantly different than the runoff volume from the conventional tillage treatment ($p \leq 0.10$).

Analysis of the runoff data according to manure and oilseed radish treatment showed averages of 8.3, 7.0 and 5.7 L/m^2 from the summer manure + radish, summer manure and spring manure treatments respectively. Runoff volumes were significantly greater from the summer manure + oilseed radish treatment than from the spring manure treatment (Table 5.10).

The plots that had a summer manure application and a fall oilseed radish crop had the most runoff for all tillage systems except the conventional system, which completely incorporated the oilseed radish. One of the purported benefits of the oilseed radish is that its tap root system fractures the soil, creating macropores which enhance drainage. The results of the May 1990 rainfall simulations would indicate that any soil structural improvements due to an oilseed radish crop do not last until late spring. Once the oilseed radish crop has been

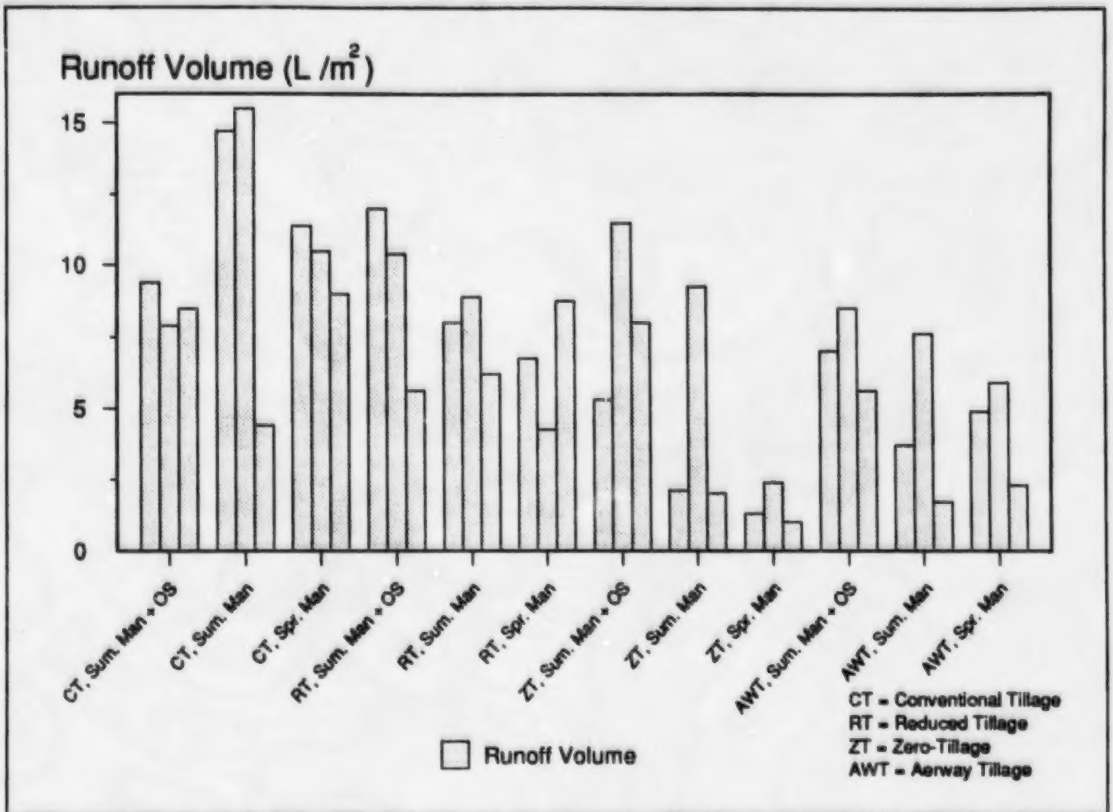

Figure 5.8a. Runoff volumes from each rainfall simulation conducted at the Q. Martin farm in May, 1990.

winterkilled, it does not appear to provide lasting soil structural benefits.

Runoff volume from the spring manure treatments averaged 5.7 L/m^2 and was significantly less than the 8.3 L/m^2 average runoff from the summer manure + oilseed radish treatment, but not significantly different than the 7.0 L/m^2 average runoff from the summer manure (no oilseed radish) treatment. Runoff from spring manure treatment was not expected to differ from the other treatments, since the same manure incorporation technique was used within each tillage category, regardless of whether spring manure was applied.

SOIL LOSS:

The concentrations of sediment in the runoff were fairly uniform for all treatments except the conventional tillage treatment (Figure 5.8b). The high sediment concentrations for the conventional tillage treatment, coupled with high runoff volumes, resulted in very high soil losses from the conventional tillage treatment (Table 5.10). The aerwayed, zero-till and reduced tillage sites had average sediment losses of 53.5 g/m^2, 56.9 g/m^2 and 77.8 g/m^2

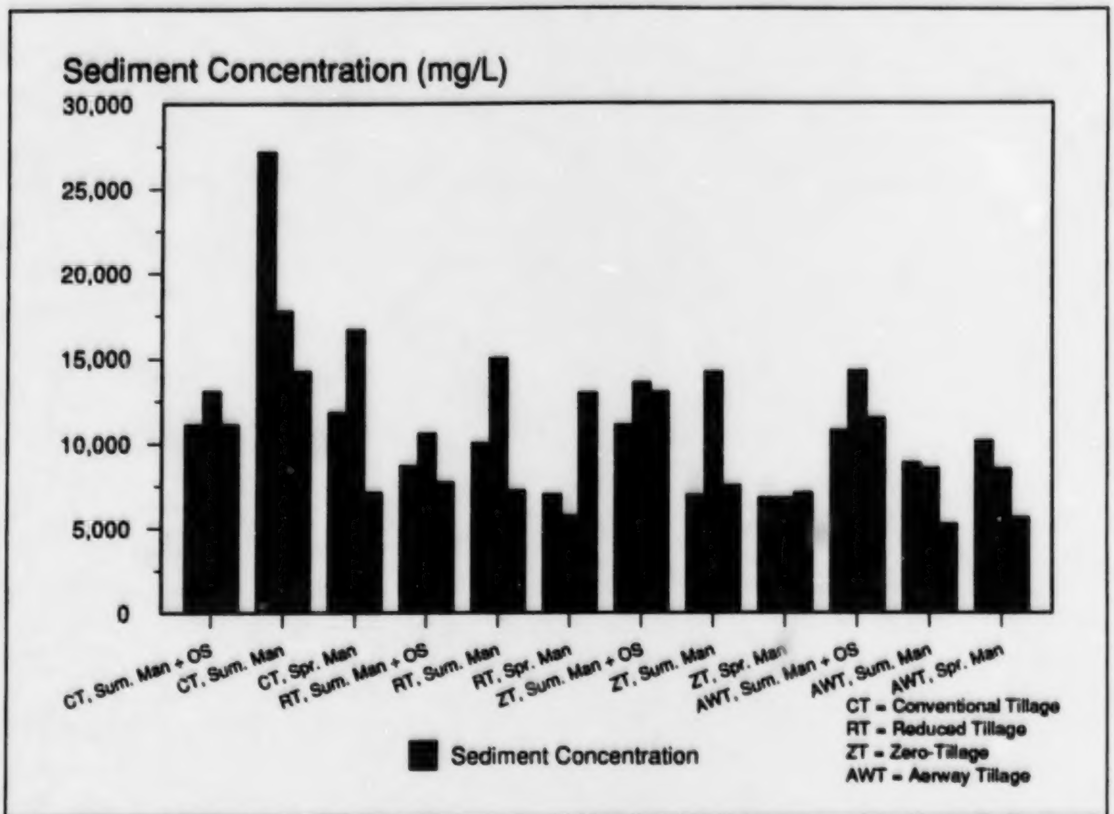

Figure 5.8b. Sediment concentrations from each rainfall simulation conducted at the Q. Martin farm in May, 1990.

respectively. All of these sediment losses were significantly less than the average 156.9 g/m^2 sediment loss from the conventional tillage treatment.

None of the comparisons by manure management system showed significant differences in terms of soil loss.

PHOSPHORUS LOSS:

The concentration of phosphorus in the sediment ranged from 0.58 to 0.76 g/kg, averaged 0.64 g/kg and did not differ significantly amongst tillage or manure treatments. The average sediment phosphorus loss ranged from a low of 6.8 mg/m^2 for the zero-till/spring manure treatment to a high of 159.5 mg/m^2 for the conventional tillage/summer manure (no oilseed radish) treatment (Table 5.10).

All three of the alternate tillage treatments had significantly less sediment phosphorus loss than the average for the conventional treatment (99.7 mg/m^2). The aerwayed and zero-till

treatments had the lowest average sediment phosphorus losses, at 34.5 mg/m^2 and 34.9 mg/m^2 respectively, while the average for the reduced tillage treatments was 52.8 mg/m^2.

Sediment phosphorus losses between the different manure/cover crop management systems did not differ significantly.

The concentration of soluble orthophosphate-P in the runoff was below the 0.01 mg/L level of detection for all of the treatments.

SUMMARY:

Runoff and soil and phosphorus losses were significantly affected by tillage treatment but not by the manure/cover crop treatment. Both the zero-till and spring aerway treatments had significantly less runoff, soil and phosphorus loss than the conventional tillage treatment. Although the reduced tillage treatment did not generate significantly less runoff than the conventional treatment, soil and sediment phosphorus losses were significantly less.

A spring manure application did not increase the susceptibility of the soil to phosphorus losses, in comparison with a summer manure + oilseed radish treatment. In late spring, a winterkilled oilseed radish crop provided no benefits in terms of erosion control.

6. Study Findings: Year 3 (1991 Field Season)

Rainfall simulations were conducted in May and June of 1991 at the farms of eight TED research cooperators. Runoff, soil and phosphorus losses were measured on the research plots of experiments dealing with cover crops, reduced tillage and aeration tillage. In addition, rainfall simulation data were obtained from a site where the same cropping system was tested at three different slopes. The latter tests were an attempt to determine the effect of changes in gradient on runoff volume and sediment and phosphorus losses.

Simulations were conducted either before planting or shortly after planting. The lack of vegetative cover at this time leaves farm soils vulnerable to erosion.

6.1 Effects of a Barley Cover Crop on Runoff and Sediment and Phosphorus Losses (B. Wood Farm, May 1991)

6.1.1 Site Description

Rainfall simulation was used to assess whether the increased amount of surface residue and possible soil structural improvements resulting from a winter cover crop were providing any lasting erosion control benefits the following spring.

The research plots were located on the farm of B. Wood, near St. Paul's Station in Downie Township, Perth County. In September of 1990, a barley cover crop was planted into a standing soybean crop and allowed to winter kill. Some of the barley was not winter killed. Two days before rainfall simulations were conducted, the cover crop and control (no cover crop) treatments were cultivated with two passes. Rainfall simulation was carried out on May 2, 1991, immediately before planting.

The composite sample of the surface soil at the site had a silt loam texture with a soil test phosphorus level of 28 mg/kg, a pH of 7.3 and an organic matter content of 3.1%. The runoff collection troughs were oriented perpendicular to the direction of the slope. Tillage operations had been conducted parallel to (i.e. "up and down") the slope of the field.

6.1.2 Statistical Analyses

Statistical analyses were conducted on the data from the two cropping systems using the Student's *t*-test. Significance was determined at $p \leq 0.10$.

6.1.3 Results and Discussion

Ground cover and Slope:

The mean percentage residue cover was 24% for the barley plots and 21% for the control (Table 6.1). The similarity in residue cover was likely the result of the thorough cultivation that both treatments received in preparation for planting.

Table 6.1. Data from Rainfall Simulations Conducted on May 2-3, 1991, at the Farm of B. Wood, Perth County. (154.8 mm/h intensity for 15 minutes)

Treatment	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Barley	2.6 a	24 a	20.2 b	5.8 a	4.9 a	5.50 a	0.53 a
Control	3.0 a	21 a	22.4 a	10.0 a	8.9 a	10.53 a	0.46 a

Means in the same column with different letters are significantly different at the 0.10 probability level.

The slopes of the barley cover crop and control treatments averaged 2.6% and 3.0% respectively and were not significantly different.

Soil moisture:

At the time of the rainulator studies, the average gravimetric soil moisture contents of the cover crop treatment was 20.2%, significantly lower than the 22.4% average soil moisture in the plot where no cover crop had been grown. The drier soil of the cover crop treatment was likely the result of moisture uptake by the barley crop, some of which had overwintered.

Runoff Volume:

Although the average amount of runoff from the control treatment was 10.0 L/m^2, nearly double the 5.8 L/m^2 average volume from the barley cover crop treatment (Table 6.1), the difference was not statistically significant (probability = 0.173). The lack of significance is attributed to variability within treatments, in particular, one low (2.2 L/m^2) runoff yielding rainfall simulation from the control treatment (Figure 6.1).

Surface infiltration on both treatments was probably increased by the field cultivation that occurred two days prior to the rainfall simulations. This field operation broke up any surface crust that may have been present.

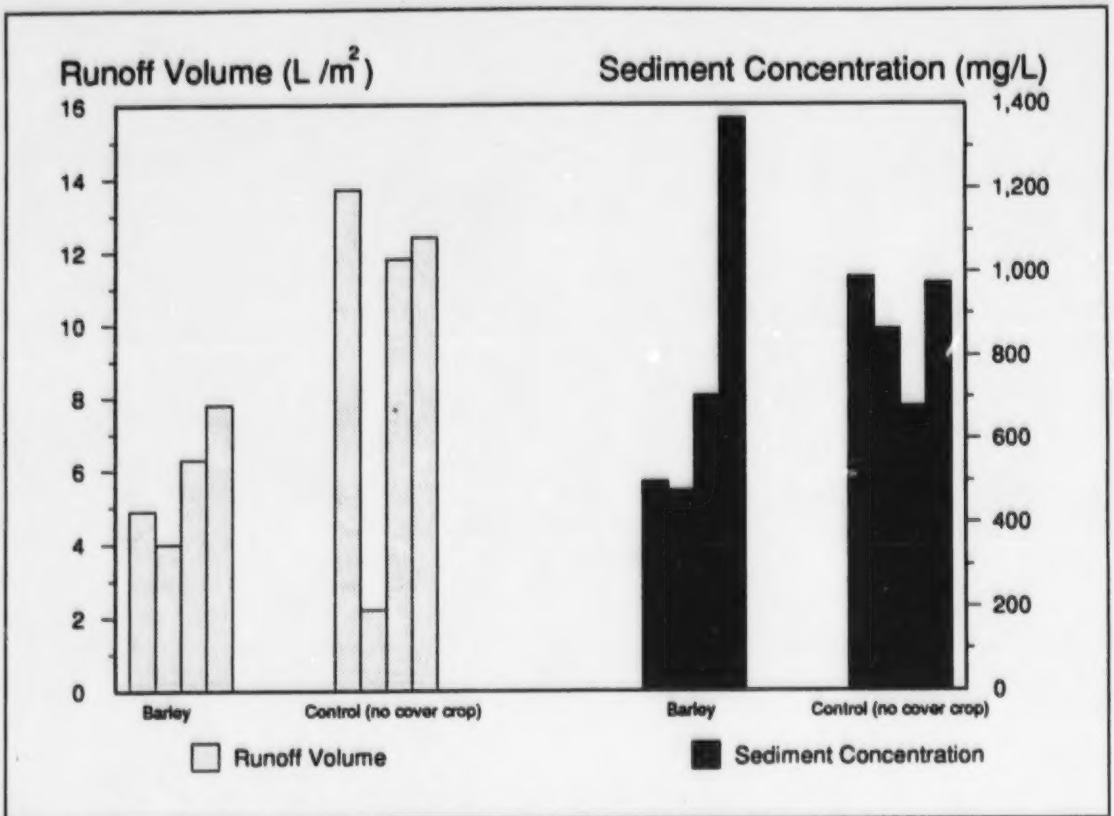

Figure 6.1. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the B. Wood farm in May, 1991.

SOIL LOSS:

The soil surface disturbance from the two passes with the cultivator resulted in high sediment concentrations in the runoff from both treatments, ranging from 477 to 1366 mg/L (Figure 6.1). Average soil loss, calculated by multiplying the sediment concentrations by the runoff volumes, was 4.9 g/m^2 from the barley cover crop plots and 8.9 g/m^2 from the control plots (Table 6.1). Soil loss was not significantly different between treatments.

PHOSPHORUS:

The concentration of phosphorus in the sediment was similar between treatments, ranging from 1065 to 1260 mg/L. Sediment phosphorus losses from the control treatment averaged 10.53 mg/m^2 and were almost twice as high as those from the cover crop treatment, which averaged 5.50 mg/m^2. It is reasonable to expect this variation since runoff volumes and soil loss averages were proportionately higher from the control treatment than the cover crop treatment. The difference in sediment phosphorus losses was not statistically significant between treatments.

Soluble orthophosphate-P concentrations in the cover crop runoff averaged 0.08 mg/L, while the concentration in the control treatment runoff averaged 0.04 mg/L. The barley cover crop treatment had an average orthophosphate-P loss of 0.53 mg/m^2, which was not significantly different from the average control treatment loss of 0.46 mg/m^2.

SUMMARY:

No significant benefits in terms of erosion control were provided at planting time by the fall planted barley cover crop. Due to the thorough cultivation and seed bed preparation immediately before the rainfall simulations, it is not known what, if any, erosion control benefits were provided by the cover crop during the winter and early spring.

6.2 EROSION CONTROL RESULTING FROM AN AERATION TILLAGE SYSTEM VS. A CONVENTIONAL TILLAGE SYSTEM (M. KLYNSTRA FARM, MAY 1991)

6.2.1 SITE DESCRIPTION

Rainfall simulation was used to test the effects of an aeration tillage system on the amount of runoff, sediment and phosphorus losses at the farm of M. Klynstra, West Oxford Township, Oxford County. A moldboard plow treatment was used to provide a conventional comparison with the aerway treatment. Tests were conducted on field plots which had been either aerwayed or moldboard plowed in late December of 1990.

Corn was grown on both field strips in 1990, along with a companion crop of oats, which was planted in July of 1990. Prior to the late December tillage, both field strips had received an application of poultry manure.

A composite surface soil sample obtained from the site had a silt loam texture with a soil test phosphorus level of 18 mg/kg, a pH of 7.1 and an organic matter content of 3.7%.

6.2.2 STATISTICAL ANALYSES

Statistical analyses were conducted on the data from the two tillage systems using the Student's *t*-test. Significance was determined at $p \leq 0.10$.

6.2.3 RESULTS AND DISCUSSION

GROUND COVER AND SLOPE:

The surface residue on the aerwayed treatment consisted largely of corn trash and oat straw, and averaged 90%, significantly greater than the 5% average residue cover measured on the moldboard plow control treatment (Table 6.2). Most of the corn trash and oat straw had been buried below the surface of the moldboard plowed plots.

Table 6.2. Data from Rainfall Simulations Conducted on May 8-9, 1991, at the Farm of M. Klynstra, Oxford County. (154.8 mm/h intensity for 15 minutes)

Tillage	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Aerwayed	4.0 a	90 a	25.8 b	12.6 a	0.5 a	0.47 a	3.63 a
Moldboard Plow Control	4.3 a	5 b	27.6 a	3.5 a	5.1 a	3.31 a	0.13 b

Means in the same column with different letters are significantly different at the 0.10 probability level.

Slopes within the rainfall plots ranged from 2.5% to 8.0%, and averaged 4.0% and 4.3% for the aerwayed and moldboard plowed treatments respectively (Table 6.2). The slopes did not differ significantly between treatments. The direction of tillage and the newly planted soybean rows for both of the treatments was parallel to the slope.

SOIL MOISTURE:

The mean gravimetric soil moisture content of 27.6% for the moldboard plowed treatment was significantly greater than the mean of 25.8% for the aerwayed treatment. The rougher surface of the plowed treatment may have allowed more of the previous natural rainfall to infiltrate into the soil prior to the simulations. Soil cracks were observed on both treatments, but they were more extensive in the soil that had been moldboard plowed.

RUNOFF VOLUME:

Although the average volume of runoff obtained from the aerwayed treatment plots (12.6 L/m^2) was more than three times as much as from the moldboard plowed plots (3.5 L/m^2), the difference was not significant (Table 6.2). The lack of statistical difference ($p = 0.154$) can be attributed to the wide variability in the runoff volumes within each treatment (Figure 6.2). Soil cracks were noted on the surface of the first aerwayed plot on which simulations were conducted and probably contributed to the reduced runoff volume from that plot.

The moldboard plowed plots had a rougher surface and more extensive soil cracking than the aerwayed plots. These factors appeared to affect the amount of runoff. On three of the four moldboard plowed plots, ponded water drained into soil cracks for the duration of the simulation (15 minutes). The field is tile drained and some of the soil cracks extended very deep, possibly down to the tile line.

SOIL LOSS:

The sediment concentration of the runoff from the aerwayed plots ranged between 16 and 52 mg/L and was significantly less ($p=0.002$) than the sediment concentration of the runoff from the moldboard plowed plots, which ranged between 624 and 1671 mg/L (Figure 6.2).

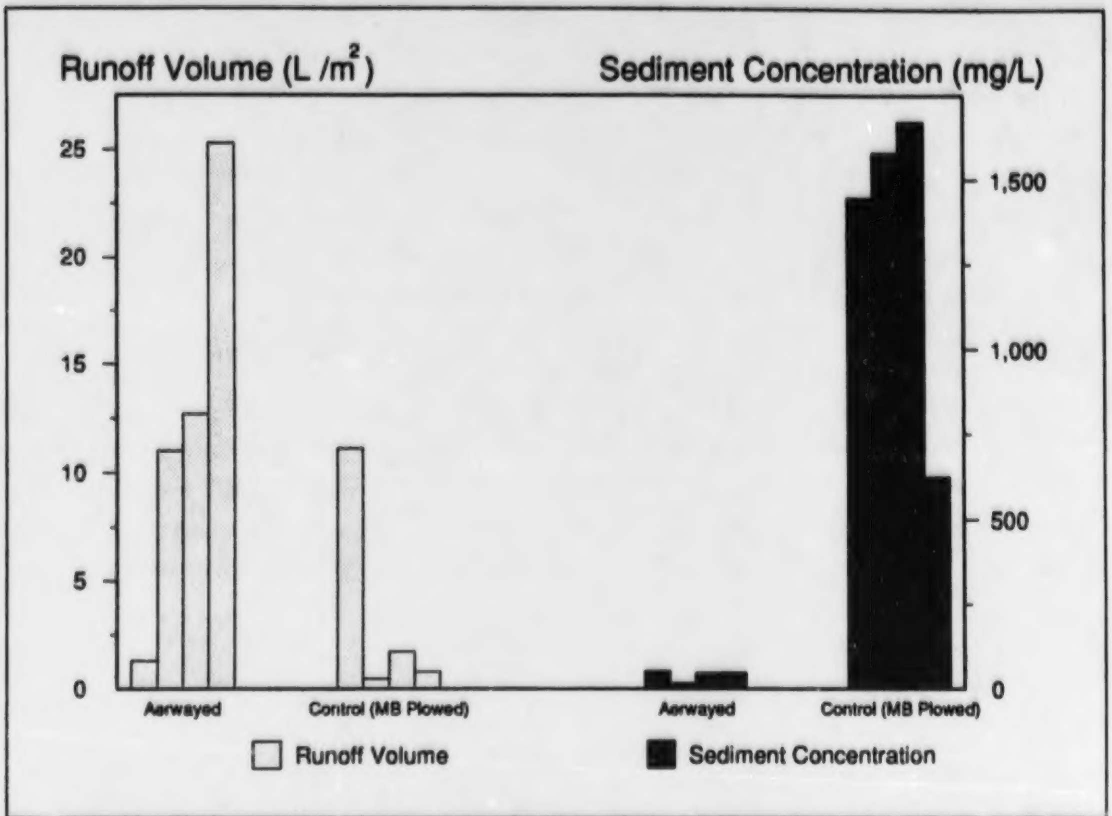

Figure 6.2. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the M. Klynstra farm in May, 1991.

The average sediment losses from the aerwayed and moldboard plowed treatments were 0.5 g/m^2 and 5.1 g/m^2 respectively. This ten fold difference in average sediment loss was not statistically significant (Table 6.2), largely due to the wide variation in runoff volumes. On the first of the moldboard plowed plots, the combination of the 11.1 L/m^2 runoff and 1446.3 mg/L sediment concentration resulted in a sediment loss value of 16.1 L/m^2. This value raised the average value for sediment loss from the moldboard plowed treatment considerably.

PHOSPHORUS LOSS:

The average phosphorus concentration of the sediment in the runoff from the aerwayed treatment was 882 mg/kg, compared to a 739 mg/kg average from the moldboard plowed treatment. Although the difference was not significant, lack of incorporation of the December manure application may have contributed to the greater sediment phosphorus concentration from the aerwayed treatment.

Sediment phosphorus losses from the two different treatments are shown in Table 6.2. Since sediment losses from the moldboard plowed treatment were much greater than those from the aerwayed treatment, sediment phosphorus losses were also greater from the moldboard plowed treatment. Although the average sediment phosphorus loss from the moldboard plowed treatment was over seven times greater than from the aerwayed treatment, the difference was not significant at $p \leq 0.10$. As with the soil loss calculations, the sediment phosphorus losses from the first rainfall simulation plot on the moldboard plowed treatment (10.1 mg/m^2), raised the overall average disproportionately.

Soluble orthophosphate-P concentrations averaged 0.42 and 0.04 mg/L in the runoff from the aerwayed and moldboard plowed treatments respectively. The losses of soluble orthophosphate-P were significantly greater from the aerwayed treatment 3.63 mg/m^2 than from the moldboard plowed treatment (0.13 mg/m^2) (Table 6.2). Unlike the moldboard plow, the aerway did not bury the manure and surface residue below the soil surface. It is likely that this difference between the tillage systems was the main reason for the greater losses of soluble orthophosphate-P from the aerwayed treatment.

SUMMARY:

Two different fall tillage treatments were compared. Average soil erosion and sediment phosphorus losses were 10 and 6.5 times greater, respectively, from the moldboard plowed treatment than the aerwayed treatment. Due to variability within each treatment, the differences were not significant at $p \leq 0.10$.

Although the average runoff volume from the aerwayed treatment was more than three times greater than from the moldboard plowed treatment, the difference was not significant. However, the combination of increased runoff and a higher concentration of soluble orthophosphate-P in the runoff from the aerwayed treatment resulted in a significantly greater loss of soluble orthophosphate-P from the aerwayed treatment.

6.3 EFFECTS OF AERATION TILLAGE VS. DISK TILLAGE ON RUNOFF AND SEDIMENT AND PHOSPHORUS LOSSES (J. VAN DORP FARM, MAY 1991)

6.3.1 SITE DESCRIPTION

Rainfall simulation was used to test the effect of two different spring tillage methods, alone and in combination, on the amount of runoff and the resulting sediment and phosphorus losses. The research plots were situated at the farm of J. Van Dorp, located in West Oxford Township, Oxford County. The field used in the 1991 simulations had been in corn for 15 years and was not the same field used for rainfall simulations at the Van Dorp farm in 1989 and 1990. The latter field was unavailable for rainfall simulations in 1991.

Three treatments were applied to the test field, including Aerway® (an aeration tillage tool) only, disk only, and an Aerway® plus disk treatment. The disking took place on May 8th. The aeration tillage treatments and planting took place on May 10, three days before the rainfall simulations. The Aerway® and planter were pulled in tandem, accomplishing both operations with a single pass. The direction of tillage and planting was perpendicular to the slope of the land.

The composite surface soil sample from the site had a loam texture with a soil test phosphorus level of 28 mg/kg, a pH of 7.1 and an organic matter content of 2.9%.

6.3.2 Statistical Analyses

Statistical analyses were conducted on data using multiple comparisons (Duncan's multiple-range). Significance was determined at $p \leq 0.10$.

6.3.3 Results and Discussion

Ground cover and slope:

The average ground cover and slopes of the three treatments used for the simulations are shown in Table 6.3. Along with trash from the previous year's corn crop, a fair number of dead weeds (mainly foxtail) contributed to the surface residue cover on all treatments. The disked soil had an average residue cover of 45%, while the aerwayed and aerwayed plus disked plots averaged 42% and 28% residue cover respectively. The difference in residue cover between treatments was not significant. The plots that had been disked had prominent trash ridges, whereas the residue was more evenly distributed on the aerwayed treatment.

Table 6.3. Data from Rainfall Simulations Conducted on May 13-14, 1991, at the Farm of J. Van Dorp, Oxford County. (154.8 mm/h intensity for 15 minutes)

Tillage	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)	Ortho P Loss (mg/m²)
Aerway Only	6.3 a	42 a	20.9 a	3.0 a	1.2 a	1.39 a	2.45 a
Disk Only	6.0 a	45 a	19.9 a	0.5 b	0.2 b	0.21 b	0.58 b
Aerwayed and Disked	5.3 a	28 a	20.3 a	0.7 b	0.3 b	0.32 b	0.27 b

Means in the same column with different letters are significantly different at the 0.10 probability level.

The slopes of the aerwayed, disked and aerwayed plus disked simulation plots averaged 6.3%, 6.0% and 5.3% respectively (Table 6.3). The differences in slope were not significant. Due to the cross-slope tillage and planting pattern, the microtopography of each of the plots

consisted of a series of trash ridges running across the slope, particularly where the disk had been used.

SOIL MOISTURE:

At the time of the May simulations, the soil moisture content was similar for the three treatments, with average gravimetric moisture contents of 20.9%, 19.9% and 20.3% respectively for the aerwayed, disked and aerwayed plus disked plots (Table 6.3). The similarity in soil moisture is to be expected, since the different tillage treatments were conducted only three days before the soils were sampled.

RUNOFF VOLUME:

The 15 minute rainfall simulations generated very little runoff from any of the treatments (Figure 6.3). The loam soil appeared to have very good infiltration properties. In most cases where the disk had been used, the upper side of the $1m^2$ plots contributed no runoff, due to the terracing effect of the cross-slope tillage.

Runoff volume was fairly uniform within treatments (Figure 6.3). The higher yielding (2.4 L/m^2) third repetition on the aerwayed plus disked treatment was the only one of the disked treatments where the upper half of the $1m^2$ plot contributed runoff. The plots on the aerwayed treatment had an average runoff volume of 3.0 L/m^2, significantly greater than the mean runoff volumes from the plots on the disked (0.5 L/m^2) and aerwayed plus disked (0.7 L/m^2) treatments (Table 6.3).

SOIL LOSS:

The concentration of sediment in the runoff water was highly variable for all treatments (Figure 6.3), but was generally highest in the aerwayed plus disked treatment. Since the disked and aerwayed plus disked treatments generated very little runoff, the resulting soil loss from these treatments was low (Table 6.3). The aerwayed treatment produced a greater amount of runoff and also had the highest soil loss. At 1.2 g/m^2, the soil loss from the aerwayed treatment was significantly greater than the 0.2 g/m^2 and 0.3 g/m^2 average soil losses from the disked and aerwayed plus disked treatments respectively (Table 6.3).

PHOSPHORUS LOSS:

The concentration of phosphorus in the sediment was similar between treatments, ranging from 1040 to 1320 mg/L. Sediment bound phosphorus losses from the aerwayed treatment averaged 1.39 mg/m^2 (Table 6.3), significantly more than the losses from the disked plus aerwayed and the disked treatments (0.32 mg/m^2 and 0.21 mg/m^2 respectively).

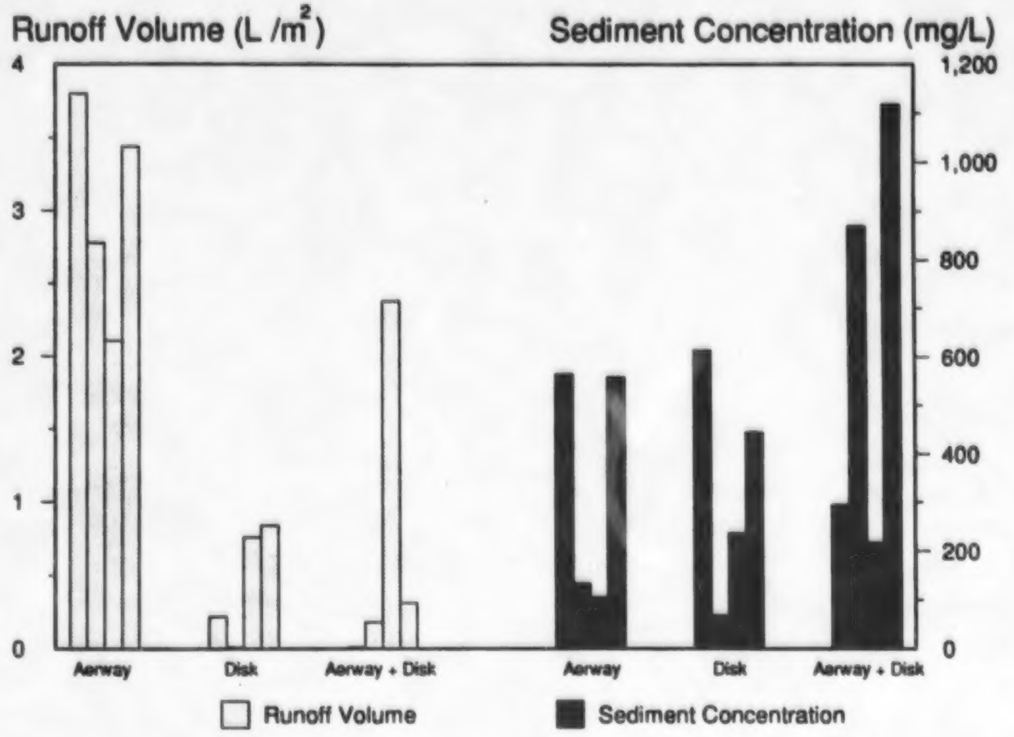

Figure 6.3. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the J. Van Dorp farm in May, 1991.

The orthophosphate-P concentrations in the runoff ranged between 0.22 and 2.44 mg/L, with averages of 1.29, 0.90 and 0.47 mg/L for the disked, aerwayed and aerwayed plus disked treatments respectively. The average orthophosphate-P losses from the aerwayed treatment were 2.45 mg/m^2, significantly greater than those from the disked (0.58 mg/m^2) and aerwayed plus disked (0.27 mg/m^2) treatments ($P \leq 0.10$).

SUMMARY:

The main factor influencing the amount of runoff from the treatments at this site appeared to be the cross-slope tillage and the resulting surface roughness and trash ridges. Since the combination of the Aerway® and planter did not produce trash ridges across the slope to the extent that the disked treatments did with the planter, the plots on the aerwayed treatment generated significantly more runoff, soil and phosphorus losses.

Virtually no runoff was generated from the disked treatments (with and without the Aerway®) by the 15 minute rainstorm. It is possible that a surface crust would develop on

the disked treatments once they had been subjected to a few weeks of baking by the sun and some heavy downpours. This crust might impede infiltration for the disked treatments more than the aerwayed treatment, due to the regular series of holes punched in the soil by the Aerway®. However, it was not feasible to test this theory, due to time constraints and the damage that would be inflicted on the corn crop.

Cross-slope tillage on this particular field is facilitated by the field's shape and the uniform slope of the land. It would appear that, during the time of year immediately following planting, when soils are considered vulnerable to water erosion due to lack of vegetative cover, this field is not at risk. Had the simulations occurred on a field that had been planted up and down the slope, the results may have been different. Also, it is not known if the ridging effect of the cross-slope tillage would continue to hold back surface runoff throughout the summer or if, with time and heavy rainfall, it would become less effective.

6.4 EFFECTS OF AN ANNUAL RYEGRASS COVER CROP ON RUNOFF AND SEDIMENT AND PHOSPHORUS LOSSES (K. GASCHO FARM, MAY 1991)

6.4.1 SITE DESCRIPTION

Rainfall simulation was used to assess whether the increased amount of surface residue and possible soil structural improvements resulting from a winter cover crop were providing any erosion control benefits the following spring. The research plots were located on the farm of K. Gascho, near the town of Zurich in Hay Township, Huron County.

In the fall of 1990, ryegrass and barley cover crops plots were planted into a standing corn crop. The barley cover crop did not establish well and was winterkilled, hence it was not tested in the May 1991 rainfall simulations. The ryegrass cover crop overwintered fairly successfully. All of the plots, including the control, were disk cultivated in mid-May, one week before the May 21-22 rainfall simulations. The fields were planted to soybeans after the rainfall simulations.

The composite surface soil sample from the site had a sandy loam texture with a pH of 8.1 and an organic matter content of 2.7%. The soil test phosphorus level was very low (3 mg/kg). However, phosphorus levels in the sediment from the runoff samples were in a similar range (1100 to 1300 mg/kg) as sediment from other sites where the soil test phosphorus level was in the 20 to 30 mg/kg range. The fact that this site was a long term organic farm, and its only fertilizer had been in the form of a fall application of composted manure may explain the low soil test P level.

6.4.2 STATISTICAL ANALYSES

Statistical analyses were conducted on the data from the two cropping systems using the Student's *t*-test. Significance was determined at $p \leq 0.10$.

6.4.3 RESULTS AND DISCUSSION

GROUND COVER AND SLOPE:

There was no significant difference between the amount of surface residue cover on the ryegrass cover crop treatment and the control plots. Most of the surface residue on both treatments was corn trash, from the previous year's crop. Residue cover averaged 28% for the ryegrass plots, and 25% for the control (Table 6.4).

Table 6.4. Data from Rainfall Simulations Conducted on May 21-22, 1991, at the Farm of K. Gascho, Huron County. (154.8 mm/h intensity for 10 minutes)

Treatment	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Ryegrass	2.5 a	28 a	11.6 a	7.9 a	0.8 a	0.98 a	0.29 a
Control	2.8 a	25 a	16.4 a	5.0 a	0.7 a	0.92 a	0.05 a

Means in the same column with different letters are significantly different at the 0.10 probability level.

The slopes of the runoff plots averaged 2.5% for the ryegrass treatment, and 2.8% for the control and were not significantly different (Table 6.4). The runoff collection troughs were oriented perpendicular to the direction of the slope. Tillage operations had been conducted parallel to the slope direction.

SOIL MOISTURE:

On May 21, the average gravimetric soil moisture contents were 11.6% and 16.4% for the ryegrass cover crop and control treatments, respectively. The moisture contents were almost significantly different ($p=0.103$). The drier soil of the cover crop treatment is likely attributable to moisture uptake by the cover crop.

It appeared that the disking had been more effective at breaking up the soil surface of the control treatment than the cover crop treatment. The drier soil surface of the ryegrass treatment may have made the soil surface more resistant to the effects of the disk.

RUNOFF VOLUME:

All but one of the rainfall repetitions on the ryegrass treatment generated more runoff than the control (Figure 6.4). One low runoff value (0.46 L/m^2) from the fourth repetition on the ryegrass treatment lowered the average runoff from this treatment (Figure 6.4). A greater

amount of disturbance to the soil surface by the disk was noted on this plot. Runoff volumes averaged 7.9 L/m^2 and 5.0 L/m^2 from the ryegrass treatment and control respectively (Table 6.4) and were not significantly different at $p \leq 0.10$.

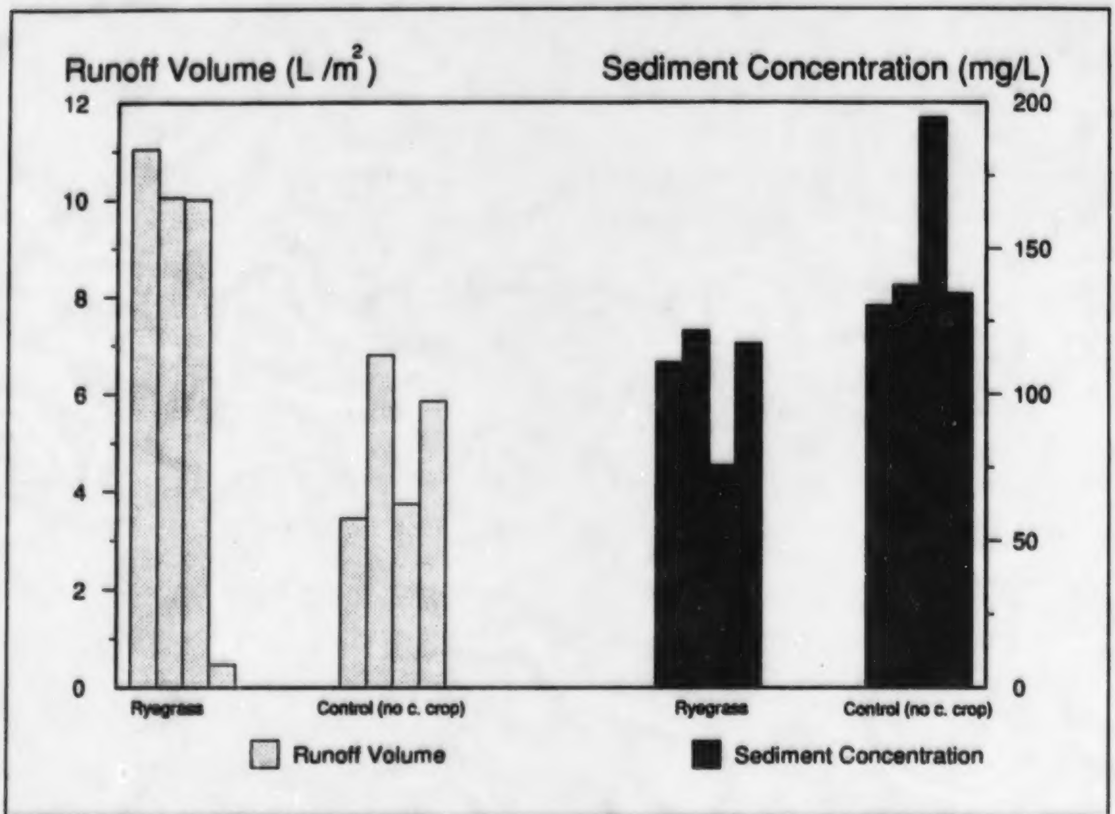

Figure 6.4. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the K. Gascho farm in May, 1991.

Soil Loss:

The concentration of sediment was higher in the runoff from the control treatment than the ryegrass treatment (Figure 6.4). The average sediment concentrations of 106.4 and 149.4 mg/L for the ryegrass and control treatments respectively were significantly different (p=0.059).

Although the sediment concentration was greater in the runoff from the control treatment, the average soil losses for the two treatments were similar, at 0.8 g/m^2 from the ryegrass plots and 0.7 g/m^2 from the control plots (Table 6.4). Thus, following a spring disking, the ryegrass cover crop did not provide any additional soil erosion control beyond that provided by the corn residue.

Phosphorus:

The average sediment phosphorus loss of 0.98 mg/m^2 from the ryegrass treatment was similar to the 0.92 mg/m^2 average loss from the control treatment (Table 6.4). As with the soil losses, the ryegrass cover crop was not helping to reduce sediment phosphorus losses at the time of the simulations.

Despite being nearly six times higher than the control treatment, the 0.29 mg/m^2 average soluble orthophosphate-P loss from the ryegrass treatment was not significantly greater than the 0.05 mg/m^2 from the control ($p=0.236$). The first repetition on the ryegrass treatment lost 0.81 mg/m^2 of soluble orthophosphate-P, while the fourth repetition had a loss of only 0.02 mg/m^2. The wide variation in soluble orthophosphate-P losses contributed to the lack of significance between treatments.

Summary:

No benefits in terms of erosion control or phosphorus loss reductions were provided at planting time by the fall planted ryegrass cover crop. The disking operation one week before the rainfall simulations seemed to have been more effective on the control treatment than on the cover crop treatment, possibly due to the moister soil of the control treatment. Disking may have had a more beneficial effect on the infiltration properties of the control treatment than the cover crop treatment.

The rainfall simulations may have been more revealing had they been conducted before the disking operations. This would have eliminated the unequal tillage effect, and the field conditions would have been more representative of the late winter and early spring period when soils are considered most susceptible to erosion (Coote *et al.*, 1988; Wall *et al.*, 1988). Unfortunately, it was not feasible to conduct the rainfall simulations any earlier at this farm in 1991.

6.5 The Effect of Fall Conservation Tillage Practices and Zero Tillage in Comparison to Fall Moldboard Plowing on Runoff and on Sediment and Phosphorus Losses (E. Devlaeminck farm, May 1991)

6.5.1 Site Description

Rainfall simulation was used to compare the relative losses of soil and phosphorus from recently planted fields under the following four tillage systems: zero tillage, fall chisel plow (twisted shovel), fall offset disk and fall moldboard plow. The rainfall simulations took place on May 23-24, 1991 at the farm of E. Devlaeminck, located near Lucan in Biddulph Township, Middlesex County.

Researchers from the Department of Crop Science at the University of Guelph were evaluating a number of different tillage systems which were conducted in the fall of 1990. The systems tested included the chisel plow with a sweep or a twisted shovel configuration, an offset disk, zero till and the moldboard plow. Some of the fall 1990 treatments were tilled when the soil was relatively dry, while others were tilled under moist soil conditions. The experiment included two fields, one with corn residue and the other with soybean residue.

All of the plots were inadvertently cultivated before they were planted in mid May of 1991, due to a misunderstanding between the researchers and the farmer cooperator. The cultivation and planting activities broke up the soil surface and dragged much of the residue to the edge of the plots. At the time of the rainfall simulations, the treatments looked fairly similar, in terms of surface residue and roughness.

Upon inspection of the plots, four of the fourteen different tillage treatments on the corn residue field were chosen for rainfall simulation. Many of the treatments were not well suited for rainfall simulation due to their location on a side sloping area of the field, thus the selection of tillage treatments was restricted. Preference was given to testing the treatments that had high residue counts the previous fall. The treatments chosen were those on which tillage had taken place the previous fall under dry soil conditions with the chisel plow with a 12 cm twisted shovel, the offset disc and the moldboard plow. The zero tillage treatment was also tested.

The composite surface soil sample from the site had a silt loam texture with a soil test phosphorus level of 29 mg/kg, a pH of 7.4 and an organic matter content of 4.5%.

6.5.2 Statistical Analyses

Statistical analyses were conducted on data using multiple comparisons (Duncan's multiple-range). Significance was determined at $p \leq 0.10$.

6.5.3 Results and Discussion

Ground cover and slope:

The average residue covers were 28%, 20%, and 19% on the zero till, chisel plow, and offset disk treatments. The moldboard plowed treatment had an average residue cover of 5%, which was significantly less than the other treatments (Table 6.5). The residue cover measured on these treatments the previous fall was 81%, 38%, 53% and 5% for the zero till, chisel plow, offset disk and moldboard plowed treatments respectively. As mentioned previously, a large amount of corn residue was removed from the plots during cultivation and planting.

Table 6.5. Data from Rainfall Simulations Conducted on May 23-24, 1991, at the Farm of E. Devlaeminck, Middlesex County. (154.8 mm/h intensity for 15 minutes)

Tillage	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Zero Till	1.9 a	28 a	23.9 b	1.0 a	0.4 b	0.46 b	0.02 a
Chisel Plow, Twisted Shovel, (12cm)	1.9 a	20 a	22.5 c	3.2 a	1.5 b	1.58 b	0.08 a
Offset Disk	2.0 a	19 a	22.7 c	2.4 a	0.7 b	0.94 b	0.08 a
Moldboard	2.6 a	5 b	25.6 a	4.6 a	4.2 a	5.05 a	0.13 a

Means in the same column with different letters are significantly different at the 0.10 probability level.

The average slope of the treatments ranged from 1.9% to 2.6%. There was no statistical difference between the slopes of any of the treatments at $p \leq 0.10$ (Table 6.5).

SOIL MOISTURE:

The soil moisture content of the moldboard plowed treatment, at 25.6%, was significantly greater than that of any of the other treatments (Table 6.5). The average soil moisture content of the zero fall tillage plots, at 23.9%, was significantly higher than the offset disk and twisted shovel treatments, where soil moisture averaged 22.7% and 22.5%, respectively. Reasons for the differences in moisture content of the various treatments may have been more apparent before the plots were cultivated and planted. The moldboard plowed treatment may have allowed more rainfall to infiltrate in the weeks prior to the simulations, due to a rougher surface.

RUNOFF VOLUME AND SOIL LOSS:

The amount of runoff measured varied widely within individual treatments (Figure 6.5). The moldboard plowed treatment had the highest average runoff, at 4.6 L/m^2, while the averages were 1.0, 2.4 and 3.2 L/m^2 for the zero till, offset disk and chisel plow treatments respectively (Table 6.5). None of the runoff volumes were significantly different.

Within each treatment, one of the four repetitions had an exceptionally high sediment concentration that raised the overall average for the treatment (Figure 6.5). The repetition with the highest sediment concentration (11,336 mg/L) occurred on the twisted shovel chisel plow treatment. Since this high sediment concentration coincided with a very low runoff volume (0.02 L/m^2), soil loss from this treatment was still quite low (0.2 g/m^2). The two rainfall simulations on the moldboard plowed treatment that had high sediment concentrations also produced a substantial amount of runoff.

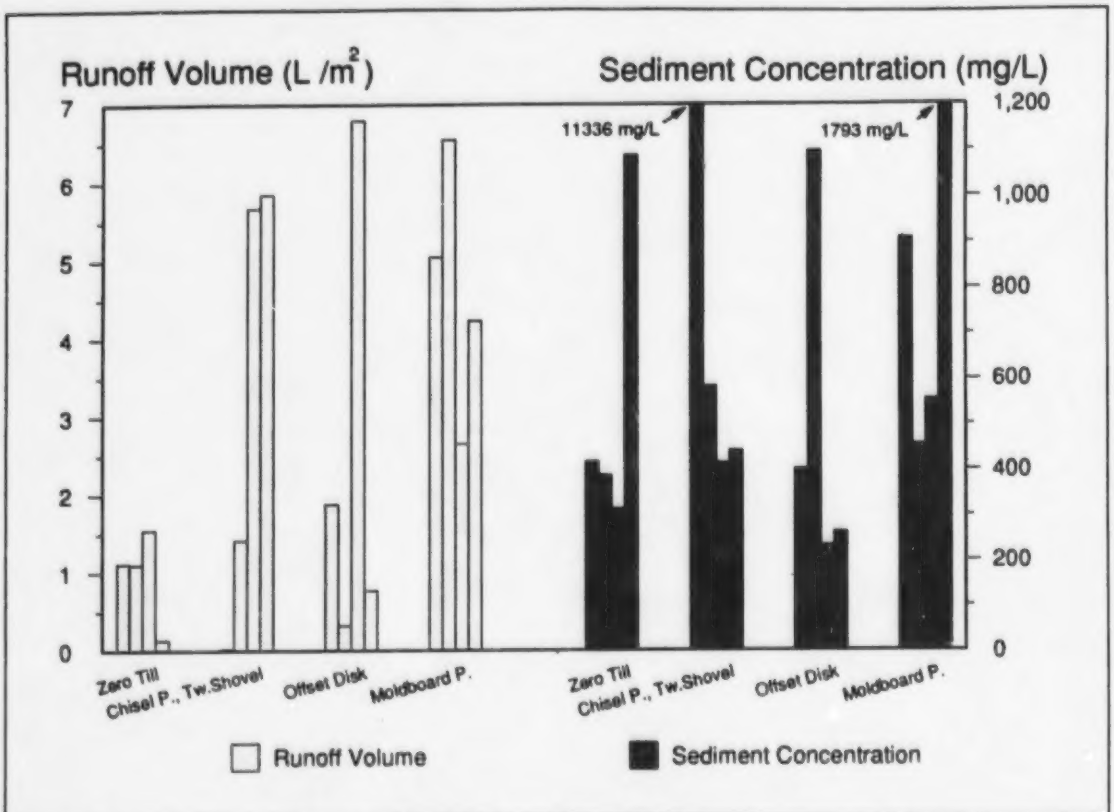

Figure 6.5. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the E. Devlaeminck in May, 1991.

The amount of soil loss from the moldboard plowed treatment, at 4.2 g/m^2, was significantly greater than the soil losses from any of the other treatments (Table 6.5). It is likely that the lower amount of residue cover on the moldboard plowed treatment contributed to the higher soil loss from this treatment.

PHOSPHORUS LOSS:

The moldboard plowed treatment had an average sediment phosphorus loss of 5.05 mg/m^2, which was significantly greater than the amount from any of the other treatments (Table 6.5).

There was no statistical difference between treatments with respect to soluble orthophosphate-P losses (Table 6.5). The moldboard plowed treatment also had the highest loss of soluble orthophosphate-P, at 0.13 mg/m^2.

SUMMARY:

The conservation tillage and zero tillage treatments all generated less runoff, and had significantly less soil loss and sediment phosphorus loss than the moldboard plowed treatment. Runoff, sediment and phosphorus losses were lowest from the zero tillage treatment, followed by the offset disk and the twisted shovel chisel plow. The low residue levels on the moldboard plowed treatment (5%) may have contributed to the greater sediment content of the runoff in comparison with the zero-till, chisel plow and offset disk treatments, which had surface residue levels of 28, 20 and 19%, respectively. There were no significant differences between the conservation and zero tillage treatments, with respect to runoff volume or soil and phosphorus loss. As expected, the results indicate that, from an erosion control standpoint, zero tillage and fall conservation tillage techniques are preferable to fall moldboard plowing.

6.6 THE EFFECT OF A WINTER RYE COVER CROP ON RUNOFF AND ON SEDIMENT AND PHOSPHORUS LOSSES (D. SMITH FARM, MAY 1991)

6.6.1 SITE DESCRIPTION

Rainfall simulation was used to test the effectiveness of a winter rye cover crop in controlling runoff, sediment and phosphorus losses. The research plots were located at the farm of Doug Smith, situated near Thamesville, in Camden Township, Kent County.

The rye was planted in the fall of 1990 into a standing winter wheat crop. In mid May of 1991, soybeans were no-till planted into both the control treatment, which contained wheat stubble residue only, and the rye treatment, which had a dense crop of rye in addition to the previous year's wheat stubble. Rainfall simulations were conducted on May 30 and 31. The rye had been sprayed with roundup 5 days before the rainfall simulations and was expected to die off in another 5 days.

The composite surface soil sample from the site had a loamy fine sand texture with a soil test phosphorus level of 21 mg/kg, a pH of 6.3 and an organic matter content of 1.9%.

The runoff collection troughs were oriented perpendicular to the direction of the slope. The rye and soybeans had been planted in alternating strips, parallel to the slope of the field. Two of the four rainfall simulation plot repetitions were conducted on the first two alternating strips of the rye and control treatments. The other two simulations were for each treatment were conducted on a different pair of alternating strips, located further from the laneway. The slope of all of the rainfall simulation plots was similar.

6.6.2 Statistical Analyses

Statistical analyses were conducted on the data from the two cropping systems using the Student's *t*-test. Significance was determined at $p \leq 0.10$.

6.6.3 Results and Discussion

Ground cover and Slope:

The surface residue cover on the control treatment consisted of stubble from the previous year's wheat crop, and averaged 57% (Table 6.6). The almost complete (95%) surface cover of the rye treatment consisted of wheat stubble and a thick cover of rye that stood about 0.4 metres high. The rye treatment had significantly more surface cover than the control (Table 6.6).

Table 6.6. Data from Rainfall Simulations Conducted on May 30-31, 1991, at the Farm of D. Smith, Kent County. (154.8 mm/h intensity for 10 minutes)

Treatment	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Rye and No-Till Soybeans	2.9 a	95 a	17.5 a	6.0 b	0.2 b	0.22 b	1.02 a
Control (No-Till Soybeans)	2.5 a	57 b	18.3 a	14.2 a	2.1 a	1.04 a	0.15 b

Means in the same column with different letters are significantly different at the 0.10 probability level.

The rainfall simulation plot slopes at the site averaged 2.9% for the rye plots and 2.5% for the control treatments. The difference in slopes was not significant at $p \leq 0.10$ (Table 6.6).

Soil Moisture:

The average gravimetric soil moisture of the rye and control plots was 17.5% and 18.3% respectively (Table 6.6). Soil moisture was not significantly different between the two treatments.

Runoff volume:

Although there was some variation within treatments (Figure 6.6), the average runoff volume from the rye treatment, at 6.0 L/m^2, was significantly less than the 14.2 L/m^2 average from the control (Table 6.6). There was very little raindrop impact on the soil below the rye due to interception by the rye canopy. Water appeared to infiltrate more rapidly into the soil below the rye treatment.

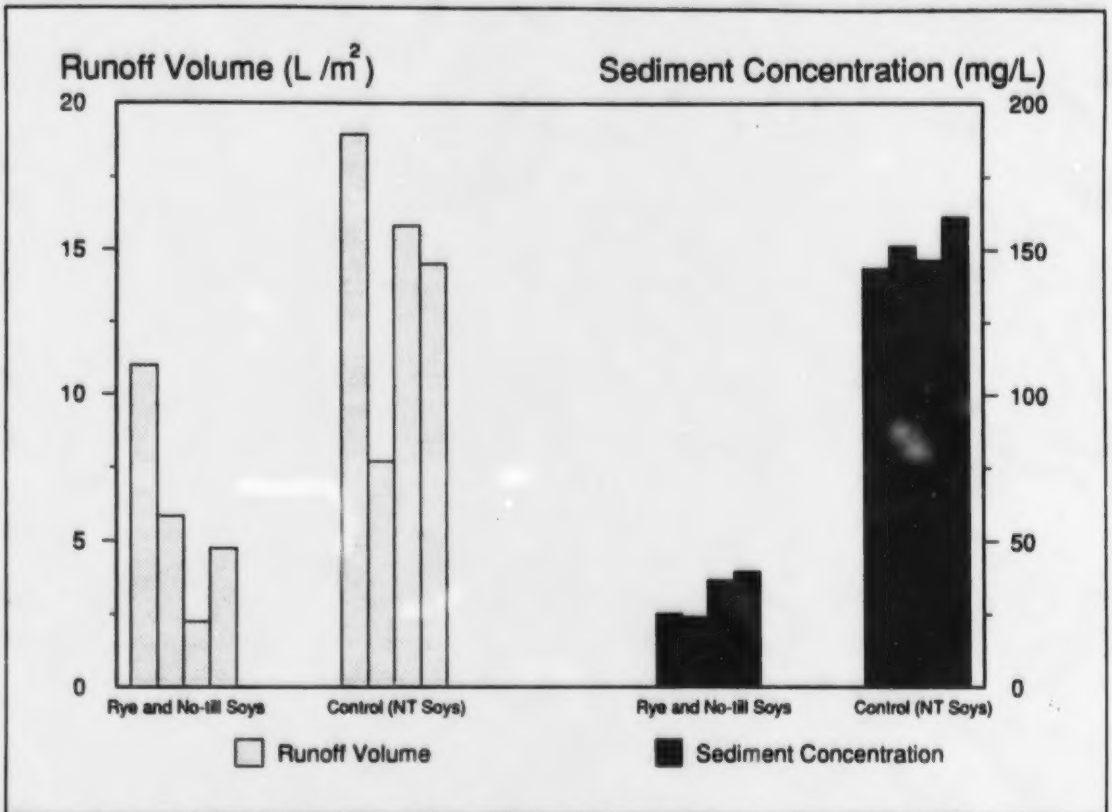

Figure 6.6. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the D. Smith farm in May, 1991.

Soil loss:

There was very little within treatment variation in sediment concentrations (Figure 6.6). The runoff from the rye treatment had the lowest concentration of sediment of all of the 1991 rainfall simulations, with an average of 31.4 mg/L. The 0.2 g/m^2 average soil loss from the rye treatment was significantly less than the 2.1 g/m^2 average loss from the control (Table 6.6). Thus, the rye cover crop was providing very effective erosion control.

Phosphorus loss:

The phosphorus concentration of the sediment found in the runoff from the rye treatment averaged 1264 mg/kg, compared to 490 mg/kg for the control. It is not known why the sediment from the rye treatment had such a high concentration of phosphorus. Neither of the treatments received any phosphorus in 1991.

Although the sediment from the rye had a higher phosphorus concentration, there was much less sediment and sediment bound phosphorus lost from the rye. The 0.22 mg/m^2

average sediment phosphorus loss from the rye treatment was significantly less than 1.04 mg/m^2 average loss from the control (Table 6.6).

The 0.20 mg/L average concentration of soluble orthophosphate-P in the runoff from the rye treatment was significantly greater than the 0.01 mg/L average from the control. Although the rye treatment produced less runoff, the much higher concentration of orthophosphate-P in the runoff resulted in a 1.02 mg/m^2 average soluble orthophosphate-P loss from the rye treatment. This amount was significantly greater than the 0.15 mg/m^2 soluble orthophosphate-P loss from the control (Table 6.6).

SUMMARY:

Rainfall simulations on a loamy fine sand soil, recently no-till planted to soybeans, with and without a rye cover crop indicated that the rye cover crop offered excellent soil erosion control. The protective canopy provided by the rye crop protected the soil surface, creating conditions that resulted in a significant reduction in the amount of surface runoff leaving the rye plots. Runoff from the rye treatment contained very little sediment and sediment phosphorus losses from the rye treatment were significantly less than those from the control. However, the concentration of soluble orthophosphate-P in the runoff was greater from the rye. As a result, the rye treatment lost significantly more soluble orthophosphate-P than the control.

6.7 THE EFFECT OF AN ANNUAL RYEGRASS COVER CROP ON RUNOFF AND ON SEDIMENT AND PHOSPHORUS LOSSES (H. SAUNDERS FARM, JUNE 1991)

6.7.1 SITE DESCRIPTION

Rainfall simulation was used to assess the effectiveness of residue from an annual ryegrass cover crop in controlling runoff and sediment and phosphorus losses from a recently planted field. The simulations were conducted on the farm of H. Saunders, located near Denfield, in London Township, Middlesex County.

The ryegrass had been planted in the fall of 1990 into a standing corn crop. The field containing both the cover crop and control treatments was planted to soybeans on May 23, 1991 and was disked three times during the week previous to the June 5-6 rainfall simulations. Most of the ryegrass was killed during the disking operation.

The composite surface soil sample obtained from the site had a silty clay loam texture with a soil test phosphorus level of 20 mg/kg, a pH of 7.2 and an organic matter content of 6.0%.

6.7.2 Statistical Analyses

Statistical analyses were conducted on the data from the two cropping systems using the Student's *t*-test. Significance was determined at $p \leq 0.10$.

6.7.3 Results and Discussion

Ground cover and Slope:

The surface cover on both treatments was augmented by the growing soybean crop, which had been planted two weeks previously. The annual ryegrass cover crop treatment had an average ground cover of 16%, which was significantly higher than the 9% average found on the control treatment (Table 6.7).

Table 6.7. Data from Rainfall Simulations Conducted on June 5-6, 1991, at the Farm of H. Saunders, Middlesex County. (154.8 mm/h intensity for 15 minutes)

Treatment	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m^2)	Soil Loss (g/m^2)	Sediment P Loss (mg/m^2)	Ortho P Loss (mg/m^2)
Ryegrass	2.1 a	16 a	29.5 a	1.3 b	0.3 b	0.37 b	0.20 a
Control	1.9 a	9 b	32.1 a	7.6 a	2.3 a	2.89 a	0.42 a

Means in the same column with different letters are significantly different at the 0.10 probability level.

The plot slopes averaged 2.1% for the annual ryegrass treatment and 1.9% for the control (Table 6.7).

Soil Moisture:

The gravimetric soil moisture content was high for both the ryegrass and control treatments, with averages of 29.5% and 32.1% respectively (Table 6.7). Water uptake by the cover crop was the likely reason for the higher moisture content of the ryegrass treatment. The moisture contents were not significantly different.

Runoff volume:

Although there was considerable variability in the runoff volumes of the four repetitions within each treatment (Figure 6.7), the ryegrass treatment consistently generated less runoff than the control. The 1.3 L/m^2 average runoff volume from the ryegrass treatment was significantly less than the 7.6 L/m^2 average runoff volume from the control (Table 6.7).

During the rainfall simulations, the silty clay loam surface soil of the ryegrass treatment appeared to have better structure than the soil of the control. As a result, the soil surface did not smooth out under the force of the raindrops as rapidly as the surface of the control. The greater surface roughness of the ryegrass treatment increased the amount of depression

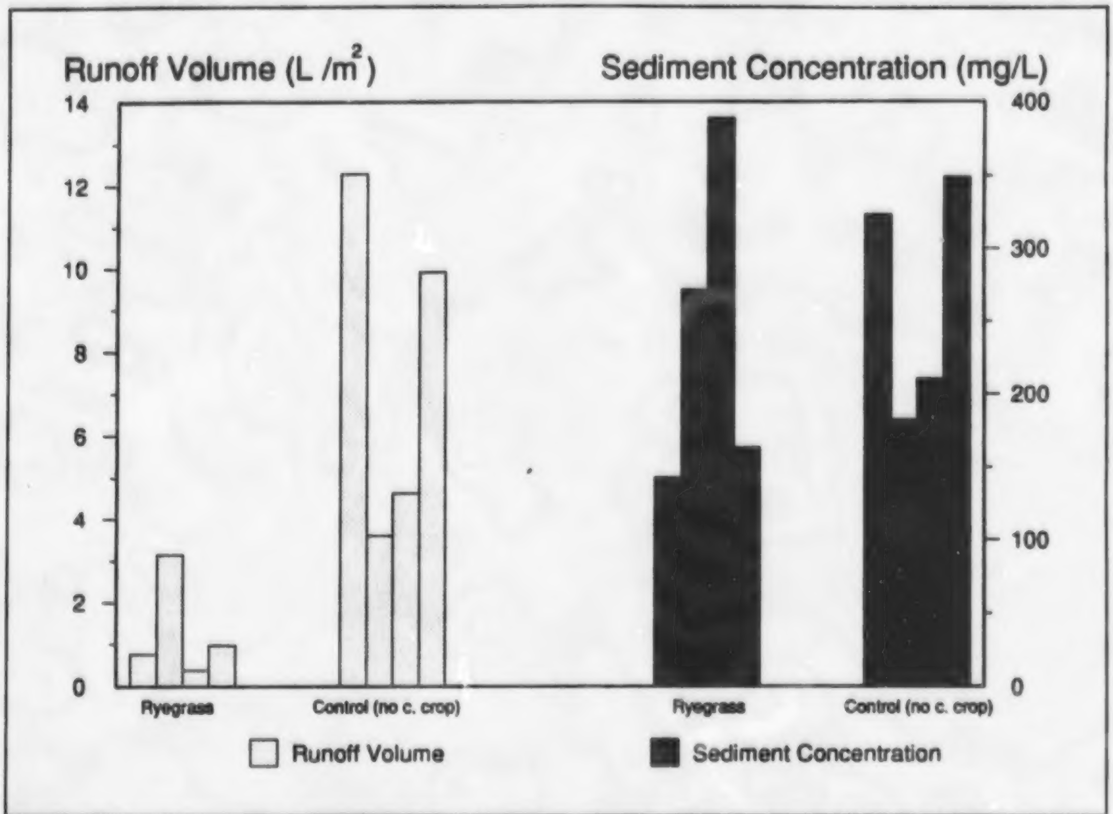

Figure 6.7. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the H. Saunders farm in June, 1991.

storage and promoted infiltration. This factor may have been the reason for the decreased amount of runoff.

SOIL LOSS:

Runoff sediment concentrations were similar for both the ryegrass treatment and the control (Figure 6.7). This was not surprising, since both treatments received the same tillage before planting. Since the ryegrass treatment generated much less runoff, the amount of soil lost from this treatment was also less. The 0.3 g/m^2 average soil loss from the ryegrass treatment was significantly less than the 2.3 g/m^2 soil loss from the control (Table 6.7).

PHOSPHORUS LOSS:

Similar concentrations of phosphorus were measured in the sediment of the ryegrass treatment and control, with averages of 1216 and 1289 mg/kg respectively. However, the lower runoff volume and sediment losses from the ryegrass treatment were also reflected in the sediment phosphorus losses. The 0.37 mg/m^2 sediment phosphorus loss from the

ryegrass treatment was significantly less than the 2.89 mg/m^2 average loss from the control (Table 6.7).

The 0.15 mg/L average concentration of soluble orthophosphate-P in the runoff from the ryegrass treatment was significantly greater than the 0.05 mg/L average from the control. However, the greater orthophosphate-P concentration in the runoff from the ryegrass treatment was more than compensated for by a reduced volume of runoff. The 0.20 mg/m^2 soluble orthophosphate-P loss from the ryegrass treatment was not significantly different than the 0.42 mg/m^2 loss from the control (Table 6.7).

SUMMARY:

On the silty clay loam soils at the H. Saunders farm, a fall planted ryegrass crop provided some lasting benefits in terms of erosion control shortly after spring planting, possibly due to improvements in soil structure. The soils of the ryegrass treatment appeared to have better soil structure and permeability. The ryegrass treatment generated, on average, about 1/6 as much runoff as the control. As a result, even though concentrations of sediment and sediment bound phosphorus were similar in the runoff from both treatments, the ryegrass treatment lost a significantly smaller amount of soil and sediment bound phosphorus.

6.8 THE EFFECT OF SLOPE ON RUNOFF AND ON SEDIMENT AND PHOSPHORUS LOSSES FROM A ROW CROPPED FIELD (G. LOBB FARM, JUNE 1991)

6.8.1 SITE DESCRIPTION

Rainfall simulation was used to gain further understanding about the effect of slope on the volume and quality of runoff. The simulations were conducted on the farm of G. Lobb, located near Clinton, in Goderich Township, Huron County.

The field where the simulations were conducted received no fall tillage and was cultivated once in the spring. Soybeans were planted in mid May into white bean residue. Rainfall simulations were carried out on June 26 and 27, 1991.

Three rainfall simulation treatments were selected, coinciding with slopes of 12%, 8% and 4%. The simulations were conducted about 15 metres from the edge of the field, adjacent to a fencerow with a laneway on the other side. To minimize damage to the soybean crop, the rainfall simulation trailer was set up on the laneway and the hoses passed through the fence to the plots on the adjacent field. The soybean crop at this location was fairly sparse, due to predation by groundhogs and fairly dry soil conditions.

Textural differences between the soils at the different slope positions were confirmed by the analytical results. The results of analysis of composite surface soil samples from the 12, 8

Table 6.8. Soil Analysis Data from Composite Samples Obtained from the Farm of G. Lobb, Huron County.

Treatment (field slope)	Texture	Sand / Silt / Clay (%)	Soil Test P (mg/kg)	pH	Organic Matter (%)
12 %	Loamy fine sand	84.2 / 11.4 / 4.5	19	7.6	1.7
8 %	Loamy fine sand	78.7 / 15.6 / 5.7	35	7.8	2.8
4 %	Fine sandy loam	69.3 / 21.5 / 9.1	23	7.8	2.9

and 4% slope positions are shown in Table 6.8. The decreasing sand and increasing silt and clay fractions as the position moved down the slope is indicative of tillage erosion, as reported by the University of Guelph under another TED contract. The higher percentage of sand at the 12% slope position may have had an effect on the rainfall simulation results.

6.8.2 Statistical Analyses

Statistical analyses were conducted on data using multiple comparisons (Duncan's multiple-range). Significance was determined at $p \leq 0.10$.

6.8.3 Results and Discussion

Ground cover and Slope:

The residue cover on the three slope treatments consisted of soybean plants and a small amount of residue from the previous year's white bean crop. The average surface cover ranged from 6% to 9%, with no significant differences between treatments (Table 6.9).

Table 6.9. Data from Rainfall Simulations Conducted on June 26-27, 1991, at the Farm of G. Lobb, Huron County. (154.8 mm/h intensity for 10 minutes)

Treatment (field slope)	Slope (%)	Residue Cover (%)	Soil Moisture (%)	Runoff Volume (L/m²)	Soil Loss (g/m²)	Sediment P Loss (mg/m²)	Ortho P Loss (mg/m²)
12 %	12.0 a	6 a	12.5 a	2.1 b	0.9 ab	0.96 b	0.08 b
8 %	8.0 b	8 a	12.8 a	2.5 b	0.5 b	0.61 b	0.13 b
4 %	4.0 c	9 a	12.1 a	6.6 a	2.2 a	2.58 a	0.27 a

Means in the same column with different letters are significantly different at the 0.10 probability level.

All of the plot slopes were within 0.5% of the intended 12, 8 and 4% treatment slopes.

SOIL MOISTURE:

The average gravimetric soil moisture of the 12, 8 and 4% slope treatments was 12.5, 12.8 and 12.1 % respectively (Table 6.9). The differences in soil moisture were not significant.

RUNOFF VOLUME:

Runoff volumes from the 12 and 8% slope treatments were similar and consistent within the same treatment while the 4% treatment had greater runoff volumes and had one repetition with a much greater volume than the other three at that slope (Figure 6.9). The 2.1 L/m^2 and 2.5 L/m^2 average runoff volumes from the 12% and 8% slopes respectively were both significantly lower than the 6.6 L/m^2 average runoff volume from the 4% slope (Table 6.9).

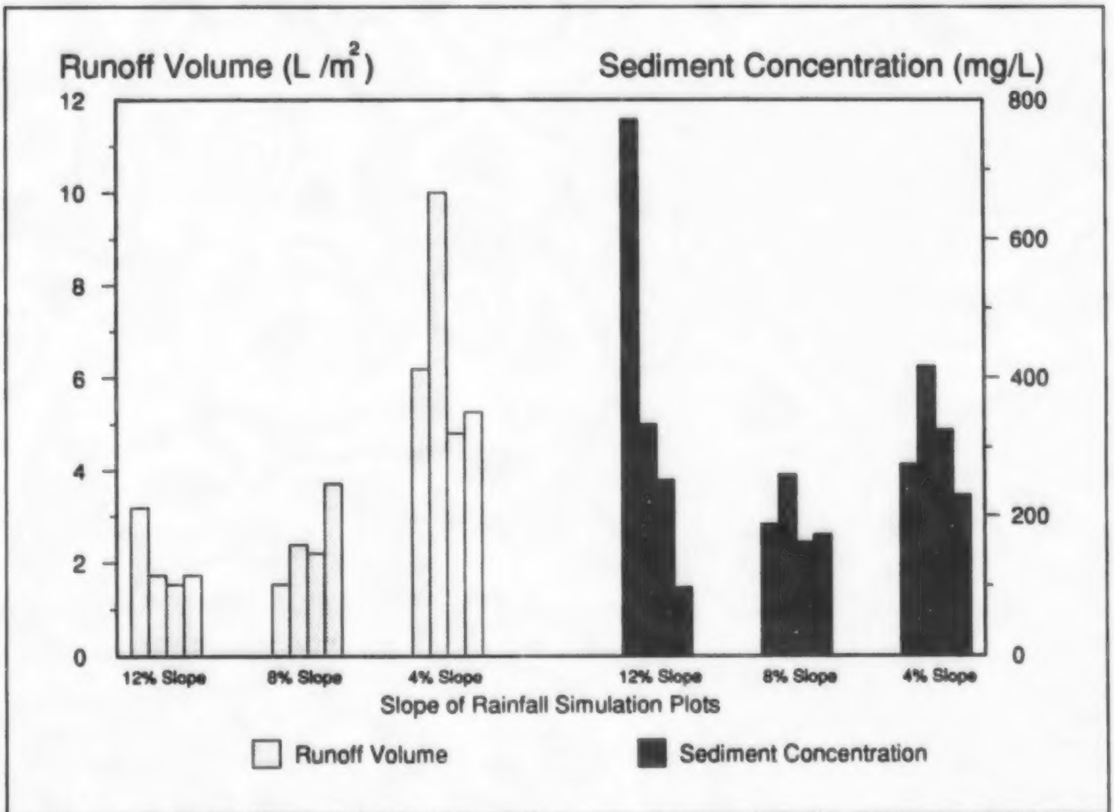

Figure 6.8. Runoff volumes and sediment concentrations from each rainfall simulation conducted at the G. Lobb farm in June, 1991.

The runoff results are contrary to water erosion theory, which predicts greater runoff volumes from steeper slopes, all other factors being equal. However, the soil texture was not the same at each slope position. The higher sand content of the steeper slope positions promoted greater infiltration of the rainwater.

SOIL LOSS:

The concentration of sediment in the runoff water was fairly uniform for all of the repetitions on the 8% and 4% slope positions (Figure 6.9). On the 12% slope position, the sediment concentration of the runoff varied widely (from 98 mg/kg to 772 mg/L). The 4% slope treatment lost the most soil due to its greater runoff volume. The 0.5 g/m^2 average soil loss from the 8% slope plots was significantly less than the 2.2 g/m^2 loss from the 4% slope (Table 6.9).

PHOSPHORUS LOSS:

Average concentrations of phosphorus in the sediment were similar at the three slope positions and ranged from 1178 to 1264 mg/kg. Due to the greater amount of runoff from the 4% slope position, the overall sediment phosphorus losses were also greater from that position. The 2.58 mg/m^2 average sediment phosphorus loss from the 4% position was significantly greater than the 0.61 and 0.96 mg/m^2 sediment P losses from the 8% and 12% slope positions respectively (Table 6.9).

Average concentrations of soluble orthophosphate-P in the runoff were similar at the three slope positions and ranged from 0.04 to 0.05 mg/L. Thus the soluble orthophosphate-P losses were proportional to the runoff volumes from the three different slope positions. The 0.27 mg/m^2 loss of soluble orthophosphate-P from the 4% slope position was significantly greater than the losses from the 8% and 12% positions, which averaged 0.13 and 0.08 mg/m^2 respectively (Table 6.9).

SUMMARY:

It was anticipated that rainfall simulations at the G. Lobb farm would provide information about the effect of plot slope on runoff volume and sediment losses. However, the soils at the site were not uniform for the three different slope positions. The upper (and steeper) slope treatments had more sand than the lower slope position. It appeared that soil texture had a greater effect on the results than the slope of the plots.

Plots on the 4% slope generated the largest volume of runoff, significantly more than the 8% and 12% slope plots. Similar concentrations of sediment, sediment phosphorus and soluble orthophosphate-P were found in the runoff from all three treatments. Thus, the greater volume of runoff also resulted in greater losses of sediment and phosphorus from plots on the 4% slope.

Efforts to quantify the effect of slope on rainfall simulation results were not successful, due to the confounding effect of differences in soil texture and associated infiltration properties. The experiment may have met with greater success on a soil with a higher silt and clay

content, as the texture might not change as much at different slope positions. Alternatively, an artificial environment with some control over the slope of the plots might prove effective for evaluating the effect of slope, all other factors being equal.

7. Summary and Conclusions

Rainfall simulations were conducted in 1989, 1990 and 1991 at a total of 14 different TED research sites. A wide range of conservation farming systems, involving tillage, cover crop and manure management systems, were evaluated in terms of runoff and soil and phosphorus losses resulting from a simulated rainstorm. The results of the rainfall simulations on the different tillage, cover crop and manure management systems on TED studies suggest that:

7.1 Tillage Treatments

1. The effects of the Aerway® tillage tool on the volume of runoff generated by rainfall simulations were inconsistent. While runoff volumes were often less from aerwayed plots than from moldboard plowed plots, in most cases, the difference was not significant (J. Van Dorp farm, May and Nov. 1990; J. Gerber farm, May 1990). On two occasions (J. Van Dorp farm, Sep. 1989 and June 1990; Q. Martin farm, May 1990) the aerwayed plots generated significantly less runoff than moldboard plowed plots. At other times there was a trend towards greater runoff from aerwayed plots in comparison to moldboard plowed plots (M. Klynstra farm, May 1990). Some of the inconsistencies may have been related to soil cracks and their effect on runoff volumes. Highly variable results were obtained when some of the rainfall simulation plots had soil cracks and others did not (J. Van Dorp farm, May 1990; M. Klynstra farm, May 1991).

2. There was a trend, significant at some sites (J. Van Dorp farm, June 1990; Q. Martin farm, May 1990) and not significant at other sites (J. Van Dorp farm, May 1990; J. Gerber farm, May 1990; M. Klynstra farm, May 1991) for runoff from aerwayed plots to have lower sediment concentrations, resulting in reduced sediment and sediment bound phosphorus losses in comparison with moldboard plowed plots.

3. Plots which were aerwayed during planting produced significantly more runoff and had higher soil, sediment phosphorus and soluble orthophosphate-P losses than plots which were disked first, then planted (with or without the Aerway®) (J. Van Dorp farm, May 1991). Tillage had been conducted across the slope, and ridges created by the disking operation appeared to have been responsible for the reduction

in runoff and associated sediment and phosphorus losses from the disked plots in comparison to the aerwayed plots.

4. Shortly after planting, soils under two different fall tillage systems (chisel plow and offset disk) and a zero-till system all yielded significantly less sediment and sediment phosphorus than soils under a fall moldboard plow tillage system (E. Devlaeminck farm, May 1991). Runoff volumes were not significantly different from the different tillage treatments. Decreased surface residue on the moldboard plowed plots (5%) as compared to the 28, 20 and 19% residue cover on the zero-till, chisel plow and offset disk treatments, may have contributed to the increased sediment losses from the moldboard plowed plots.

5. Zero-tillage reduced runoff, soil and phosphorus loss by approximately 70% compared with conventional tillage (Q. Martin farm, Nov. 1989). Fall chisel plowing, however, did not reduce runoff, soil and phosphorus losses relative to conventional tillage. The tests were conducted in November. Fall moldboard plowing left an average surface residue cover of 2%, compared to 25% residue cover after fall chisel plowing and 61% average residue cover on the zero-tillage plots.

6. Shortly after planting, zero-tillage and spring Aerway® tillage resulted in reduced runoff, soil and phosphorus losses compared to conventional (fall moldboard plow) tillage (Q. Martin farm, May 1990). Reduced tillage (fall chisel plow) resulted in reduced soil and sediment phosphorus losses, relative to conventional tillage. Residue levels at this time were 4, 15, 28 and 21% for the conventional tillage, reduced tillage, zero-tillage and aerway tillage plots respectively.

7.2 Cover Crops

1. In tests conducted shortly after planting, the magnitude of runoff, soil and phosphorus losses was significantly reduced when red clover, underseeded in winter wheat, was killed by chemical spray application as opposed to tillage (W. Tebbutt farm, May 1989; R.E. Thompson farm, May 1990).

2. No additional erosion control benefits were measured the following spring when the red clover (underseeded to wheat) was chemically

killed in the fall versus in the spring, although the residue cover on the spring killed treatments was significantly greater (W. Tebbutt farm, May 1989; R.E. Thompson farm, May 1990). Red clover, chemically killed in the fall and spring maintained residue levels of 67 and 92% respectively in May 1989, and 46 and 61% respectively in May 1990.

3. Plots having red clover and oilseed radish residue cover tended to generate more runoff and lose more sediment and sediment bound phosphorus than where the previous cover crop was hairy vetch or rye (M. Klynstra farm, June and Nov. 1990). The highest losses of soluble orthophosphate-P were from the red clover and the rye treatments. Hairy vetch appeared to provide the best and longest lasting erosion control benefits of the four cover crops tested (M. Klynstra farm, June and Nov. 1990).

4. The effects of fall planted cover crops on runoff and erosion the following spring were inconsistent. Barley residue, providing 24% surface cover in comparison with 21% cover on the control (B. Wood farm, May 1991), and annual ryegrass residue, providing 28% cover in comparison with 25% cover on the control (K. Gascho farm, May 1991), provided no significant benefits in terms of erosion control after spring cultivation. However, at one site (H. Saunders farm, June 1991), the plots on which an annual ryegrass cover crop had been grown and disked over (16% residue cover) had significantly lower runoff, sediment and sediment phosphorus losses than the control (no cover crop) plots (9% residue cover). It would appear that, when the residue cover from the main crop is high, any additional erosion control offered by cover crops is minimal.

5. After planting, runoff, sediment and sediment phosphorus losses were significantly less from plots where soybeans were no-till planted into a standing winter rye crop, compared to no-till soybeans without the rye (D. Smith farm, May 1991). However, soluble orthophosphate-P losses were significantly greater from the rye/no-till soybean treatment than the no-till soybean treatment. The rye in this management system formed a dense mulch, providing 95% surface cover, compared to 57% cover where rye was not grown.

6. In late spring, residue from a winterkilled oilseed radish crop provided no benefits in terms of erosion control (Q. Martin farm, May 1991). At this time, the residue levels on the oilseed radish treatments averaged 13%, compared to 18 and 20% residue levels on the plots without oilseed radish.

7.3 MANURE MANAGEMENT

1. A mid-summer application of either raw or composted cattle manure applied to the surface of established forages on a moderately (6.5%) sloping field had no significant effect on the amount of sediment, sediment bound phosphorus or soluble orthophosphate-P lost in surface runoff (M. Bender farm, July 1989). A perennial forage provides a complete surface cover (> 90%) and summer manure application under dry soil conditions would appear a reasonable outlet for manure.

2. Liquid swine manure applications did not increase sediment phosphorus or soluble orthophosphate losses under moldboard, chisel plow and zero-till tillage methods, with or without a cover crop of oilseed radish (Q. Martin farm, Nov. 1989). Tillage was the controlling factor in soil erosion and phosphorus losses (see Section 7.1).

3. When poultry manure was applied in the fall and incorporated by aerway tillage, soluble orthophosphate-P losses were very high (3.6 mg/m^2) the following spring (M. Klynstra farm, May 1991). Soluble orthophosphate-P losses were significantly lower (0.13 mg/m^2) where the manure had been incorporated by moldboard plowing.

7.4 EFFECT OF PLOT SLOPE

1. At some sites, treatments being compared by rainfall simulation had significantly different slopes (J. Van Dorp farm, Sep. 1989 and May 1990; R.E. Thompson farm, May 1990). The effect of the different slopes on the resulting runoff volumes, and the soil and phosphorus losses from these sites is not known, but it is generally assumed that steeper slopes generate greater amounts of runoff, all other factors being equal.

2. Based on the results of one experiment where the same tillage/cropping treatment was tested at slopes of 12, 8 and 4% (G.

Lobb farm, June 1991), it would appear that the 4% slopes generate significantly more runoff and lose more sediment and phosphorus. However, the results of this experiment were confounded by different soil properties at the different slope locations.

8. RECOMMENDATIONS

The following recommendations are suggested for future rainfall simulation studies.

1. The erosion control benefits of complete (and promising) conservation farming management systems need to be evaluated against realistic control treatments, on an ongoing basis. Runoff and erosion measurements should take place at several key times of the year, including early spring. It is recognized that a considerable number of obstacles and logistical constraints would have to be overcome before this experiment could be realized, and that the natural (versus simulated) rainfall plot research currently being conducted in southwestern Ontario under the direction of Dr. G. Wall may be fulfilling this goal.

2. Many of the farm technologies and management systems that were tested in the TED program were not evaluated by rainfall simulation. Other TED studies indicated that runoff rates from long term no-till treatments were greater than from conventional systems. Ridge till appears to be an effective management system on some soils and topographies. No-till, zone tillage and ridge tillage systems should be evaluated by rainfall simulations. The plot size and plot border system used for the rainfall simulations in this study would likely require modification in order to accommodate tests on a ridge till system.

3. The effect of surface cracking on runoff and erosion losses needs to be examined in greater detail. At sites where soil cracks are prominent, methods to assess the impact of the cracks on the results (due to runoff losses to the cracks) should be considered. This could be accomplished by wetting some plots thoroughly (allowing them to swell) before commencing the rainfall simulations, while conducting other simulations on drier, cracked soils. Alternatively, rainfall simulations at sites known to have extensive cracking could be conducted before, and a few days after a natural rainfall event.

4. The effect of plot slope on runoff and erosion losses should be examined at a number of sites. Soil analysis should be conducted in advance of the simulations, to determine if soil textural differences occur at the different slope positions.

9. References

American Public Health Association. 1975. Standard Methods for the Examination of Water and Wastewater. Fourteenth Edition. M.C. Rand, A.E. Greenberg, and M.J. Taras, editors. American Public Health Association, Washington, D.C.

Andraski, B.J., T.C. Daniel, B. Lowrey, and D.H. Mueller. 1985a. Runoff results from natural and simulated rainfall for four tillage systems. Trans. ASAE 28 (4): 1219-1225.

Andraski, B.J., D.H. Mueller, and T.C. Daniel. 1985b. Effects of tillage and rainfall simulation date on water and soil losses. Soil Sci. Soc. Am. J. 49: 1512-1517.

Atmospheric Environment Service (AES). 1986. Rainfall Intensity-Duration Frequency Statistics for Stations located at: Elora Research Station, Goderich Airport, London Airport, Mount Forest, Stratford and Woodstock.

Barisas, S.G., J.L. Baker, H.P. Johnson, and J.M. Laflen. 1978. Effect of tillage systems on runoff losses of nutrients, A rainfall simulation study. Trans. ASAE 21: 893-97.

Coote, D.R., C.A. Malcolm-McGovern, G.J. Wall, W.T. Dickinson and R.P. Rudra. 1988. Seasonal variation of erodibility indices based on shear strength and aggregate stability in some Ontario soils. Can. J. Soil Sci. 68: 405-417.

Foster, G.R. 1988. Modelling soil erosion and sediment yield. In: Soil Erosion Research Methods. R. Lal, editor. Soil and Water Conservation Society, Iowa.

Kramer, L.A. 1986. Runoff and soil loss by crop stage from conventional and conservation tilled corn. Trans. ASAE 29 (3): 774-79.

Laflen, J.M., J.L. Baker, R.O. Hartwig, W.F. Buchele, and H.P. Johnson. 1978. Soil and water loss from conservation tillage systems. Trans. ASAE 21: 881-885.

Meyer, L.D. 1988. Rainfall simulators for soil conservation research. In: Soil Erosion Research Methods. R. Lal, editor. Soil and Water Conservation Society, Iowa.

Mostaghimi, S., T.A. Dillaha, and V.O. Shanholtz. 1988. Influence of tillage systems and residue levels on runoff, sediment, and phosphorus losses. Trans. ASAE 31(1): 128-132.

Mueller, D.H., R.C. Wendt, and T.C. Daniel. 1984. Soil and water loss as affected by tillage and manure application. Soil Sci. Soc. Am. J. 48: 896-900.

Romkens, M.J.M., D.W. Nelson, and J.V. Mannering. 1973. Nitrogen and phosphorus composition of surface runoff as affected by tillage method. J. Environ. Qual. 2 (2): 292-295.

Tossell, R.W., W.T. Dickinson, R.P. Rudra and G.J. Wall. 1987. A portable rainfall simulator. Can. Agric. Eng. 29: 155-162.

Wall, G.J., W.T. Dickinson, and J. Greuel. 1983. Rainfall erosion indices for Canada east of the Rocky Mountains. Can. J. Soil Sci. 63: 271-280.

Wall, G.J., W.T. Dickinson, R.P. Rudra and D.R. Coote. 1988. Seasonal soil erodibility variation in southwestern Ontario. Can. J. Soil Sci. 68: 417-424.

Wall, G.J., E.A. Pringle and R.W. Sheard. 1991. Intercropping red clover with silage corn for soil erosion control. Can. J. Soil Sci. 71: 137-145.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses - a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.